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Solvent Metal Cleaning Air Pollution Control

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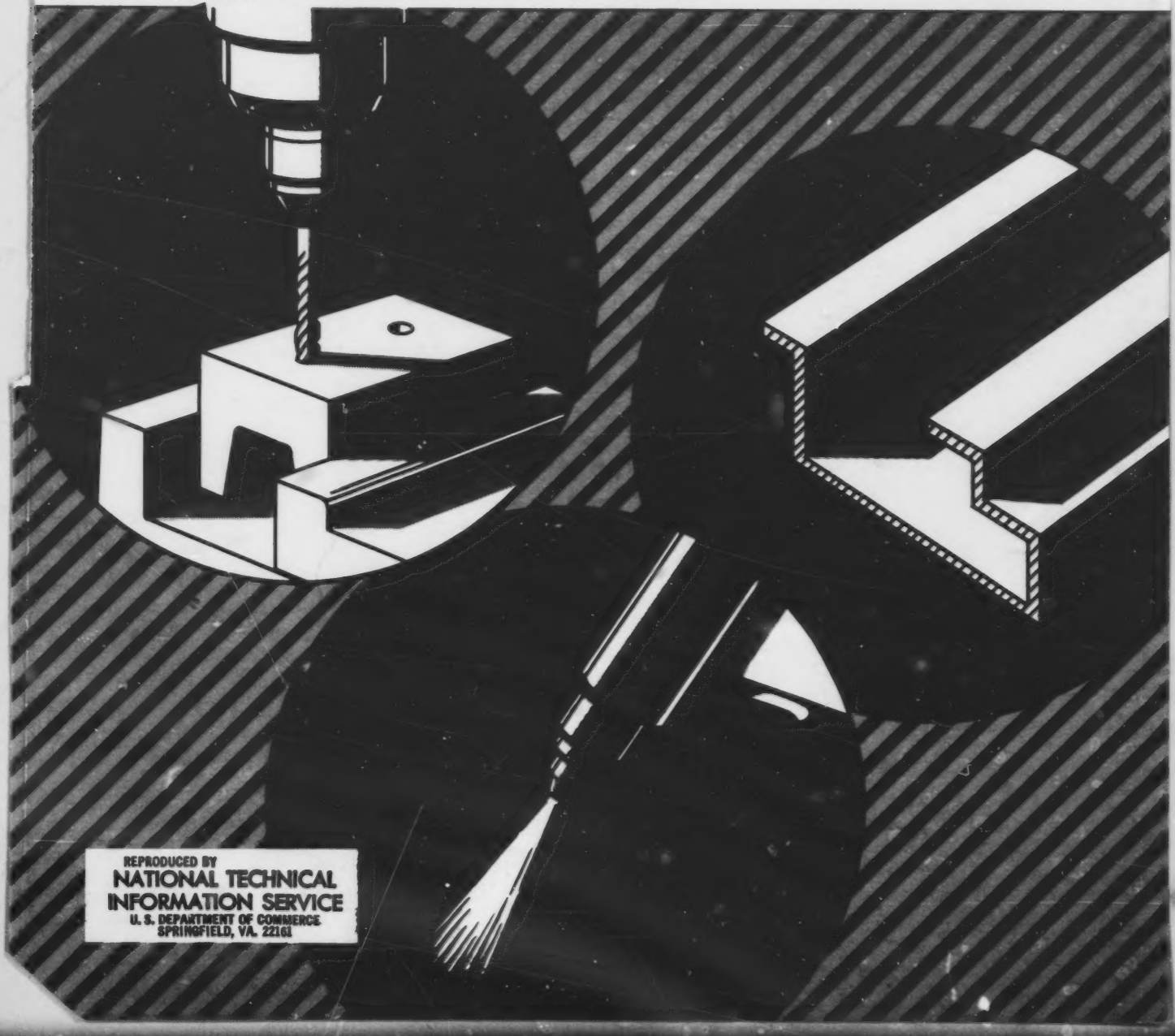

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The first volume acquaints supervisory and management personnel in the industry with methods of reducing the emission of organic solvents to the atmosphere and helps them assess the costs. Volume 2 outlines for plant operators practical and proven techniques for controlling hydrocarbon emissions from metal cleaning operations, along with appropriate cost data. Volume 3 addresses managers, engineers and other industry personnel responsible for resolving the water pollution problems of a manufacturing facility. It covers regulations, in-plant controls, three methods for wastewater treatment, establishment of a working relationship with a municipality and a case history.

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CONTROLLING POLLUTION FROM THE MANUFACTURING & COATING OF METAL PRODUCTS

SOLVENT METAL CLEANING AIR POLLUTION CONTROL – II

U.S. ENVIRONMENTAL PROTECTION AGENCY
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CHAPTER I

INTRODUCTION

Hydrocarbon emissions, generated by industry and vehicles, contribute to the photochemical atmospheric formation of oxidants that is known as smog. Vehicle emission control is under the jurisdiction of the U.S. Environmental Protection Agency (EPA); industrial emissions currently fall under state jurisdiction, as authorized in the EPA's State Implementation Plans. Twenty-two states now have controls, and their number is increasing. Emissions from new or modified industrial sources fall under control of the federal government, which will shortly be addressing the problem of solvent metal cleaning.

This publication outlines for plant operators practical and proven techniques for controlling hydrocarbon emissions from metal cleaning operations, along with cost data for the various techniques. It is not our intent to present a best practicable reduction control technology. Rather, the purpose is to give information on the various ways that representatives of the industry have reduced and controlled solvent emissions in their own operations.

Solutions must generally be plant-specific, and therefore the material should be regarded as background information rather than as an overall prescription.

CHAPTER II

METAL CLEANING METHODS

Plant personnel who are responsible for metal cleaning, newly subject to emission (air) or effluent (water) standards, must now become familiar with the techniques and equipment available for reducing pollution from cleaning operations. As background to a discussion of these techniques, however, we will briefly review the standard metal cleaning methods.

Before metal becomes a finished product, it goes through many steps—e.g., stamping, cutting, tapping, drawing, quenching, assembly, and finishing. These operations often deposit substances on the metal surfaces that must be removed before assembly or finishing operations such as enameling or painting.

We will focus here on the removal of greases for those metal finishing processes that require a surface ranging from relatively clean to very clean. The greases include lubricants, coolants, waxes, and lapping/buffing compounds.

Metal can be effectively degreased only by wet processes; dry processes, such as sand or grit blasting, are effective only for smaller batches where surface finish or dimensions are not critical. There are two major wet metal cleaning methods: water-based washing and solvent cleaning. Practical considerations usually make the choice between them obvious. These same considerations often make it impractical and uneconomic to switch from solvent to water-based cleaning to reduce hydrocarbon emissions, even though this is technically feasible. In the future, however, the economics of metal cleaning by both methods will change; effluent limitations will be imposed on wastewater from washing systems, and emission limitations may be placed on new solvent cleaning operations. The effect on relative costs, and on choice of systems, is yet to be seen.

The selection of a metal cleaning system depends on:

- The type of metal;
- The material to be removed; and
- The subsequent metal operation.

Materials to be removed are either organic (lubricating and cooling oils and waxes) or inorganic (buffing compounds, metallic oxides, and metal chip and dirt adhering to the organic substances). Lightweight mineral-oil-based lubricants and coolants are more easily removed than heavier lubricants and coolants with extreme-pressure agents like sulfur and chlorine. Buffing compounds whose emulsifiers have evaporated pose a difficult problem with both cleaning methods. Water-based lubricants and

coolants are more readily cleaned by washing methods than by solvent cleaning. Oil-based lubricants and coolants are more readily dissolved by solvents, but some light mineral oils can be cleaned with water-based solutions containing emulsifiers.

The metal itself dictates cleaning methods. Water-based cleaners may be the wrong choice for electronic parts and for ferrous parts susceptible to rust. Temperature-sensitive parts may be damaged by the relatively high temperatures of solvent-vapor degreasing. Similarly, precision parts with different coefficients of expansion cannot be exposed to boiling solutions.

Several of the final metal operations require very clean metal, which also dictates the cleaning method. Assembly of precision-cut or formed parts may be hindered by corrosive water residues from water-based washing. To achieve the cleanest possible surfaces for electroplating and enameling, parts must either be exposed to a solvent distillate vapor or a clean or deionized water rinse.

SOLVENT CLEANING

The major advantage of solvent-based cleaners is their ability to dissolve oils and greases. Two types of solvents are effective: the low-cost flammable petroleum-based solvents, and the more expensive nonflammable halogenated hydrocarbon solvents.

Solvent cleaning is performed by boiling halogenated solvents (vapor degreasing), or by cleaning at room temperatures with either petroleum or halogenated solvents (cold cleaning). The best cleaning action is achieved by vaporizing solvents and exposing the metal to the pure vapors. However, because of the flammability of petroleum solvents, this method is confined to the halogenated solvents. Both petroleum and halogenated solvents can be used in cold cleaning.

COLD CLEANING

Cold cleaning may consist of hand wiping, spraying, or dipping, or may take place in closed conveyorized systems that use tumble, dip, and spray operations. Fine sprays of petroleum solvents should be avoided in open areas because of flammability and inhalation problems. Hence, Stoddard solvents (with high boiling points) are often used for spraying a petroleum solvent. Air pollution regulations for cold cleaning are most likely to apply to tanks for dipping and spraying and to cabinets with conveyor systems. Pre-regulatory studies of air pollution regulations for new sources have not focused on hand wiping or spraying performed in a booth.

VAPOR DEGREASING

The best cleaning action is achieved by vaporizing solvents and exposing the metal to the pure vapors.

The two basic types of equipment for vapor degreasing are open top tanks and closed-conveyorized systems. Of approximately 18,000 vapor degreasing units used

in the manufacturing sector, 85 percent are open top tank and 15 percent are conveyorized systems. Open top systems are often used intermittently, while conveyor systems are generally used in mechanical production lines. Where air pollution regulations are applied, both systems are likely to be affected.

Sketches of two open top tanks and two conveyorized systems are included here as Figures 1 through 4. The difference between the two open top systems shown is the lip exhaust in the second one (Figure 2), which keeps vapors away from workers. The difference between the two conveyorized systems is that the monorail system (Figure 4) can be conveniently used in a plant equipped with a monorail on its production line.

Three cleaning stages may take place in open top tank or conveyorized vapor degreasing systems: vapor boiling, immersion, and warm immersion. The heat sources for these systems are low-temperature steam, electricity, or gas. Heavy cleaning requirements may justify the use of ultrasonic transducers in the liquid stages or of sprays in the vapor zone. Much higher-pressure spraying can be used in the conveyorized systems because emissions will not escape as readily as from an open top tank.

Five halogenated solvents are used in vapor degreasing:

Solvent	Boiling Point
Trichloroethylene	188°F
1,1,1-Trichloroethane	165°F
Perchloroethylene	250°F
Methylene chloride	104°F
Trichlorotrifluoroethane	118°F

Emission differences may be less of a factor in selecting a solvent, however, than differences in cleaning properties. High-melting grease deposits on metal may require the high-temperature cleaning power of perchloroethylene, which has the highest boiling point—250°F—of the halogenated solvents. (The use of perchloroethylene will require high-temperature steam instead of the more common low-temperature steam.) Temperature-sensitive metals may require methylene chloride (104°F boiling point) or trichlorotrifluoroethane (118°F boiling point). On the other hand, methylene chloride may be too harsh for plastics and elastomers. Energy considerations favor the low-boiling solvents. Removing water, among other things, from metal parts would require the only halogenated solvent with a boiling point above water, i.e., perchloroethylene, or the azeotropes of the other solvents.

Differences in Threshold Limit Value (TLV)—an arbitrary level of a substance (expressed in ppm) at which workers may presumably be safely exposed—may also affect a choice of solvents. The TLVs of methylene chloride (500), trichlorotrifluoroethane (1000), and 1,1,1-trichloroethane (350) are higher, for instance, than those of trichloroethylene (100) and perchloroethylene (100).

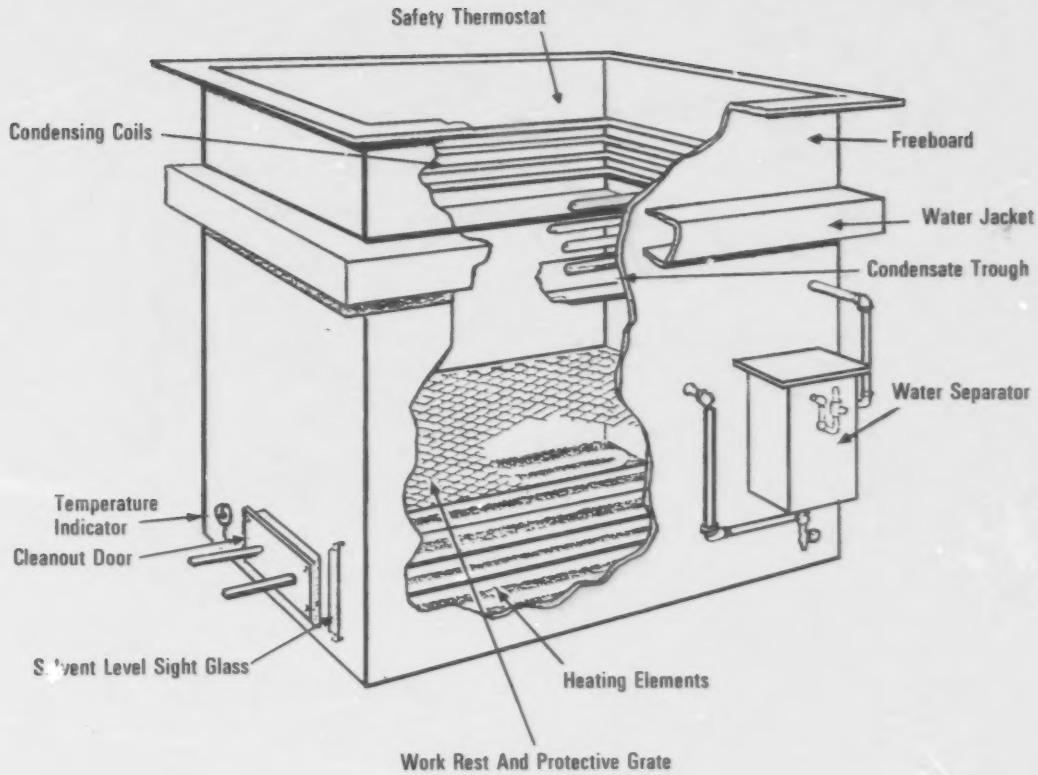


Figure 1. Open Top Vapor Degreaser

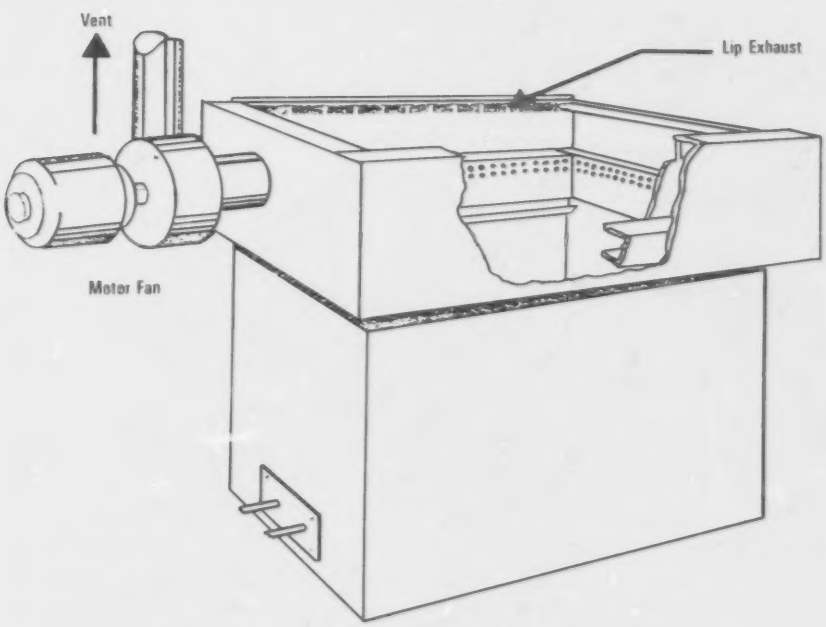


Figure 2 Open Top Vapor Degreaser with Lip Exhaust

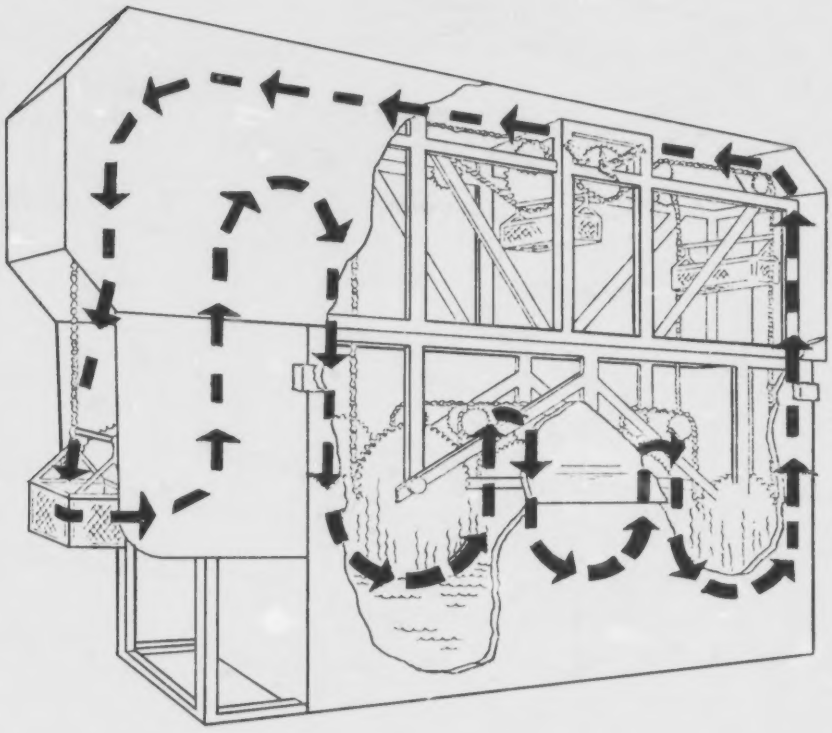


Figure 3. Cross-Rod Conveyorized Degreaser

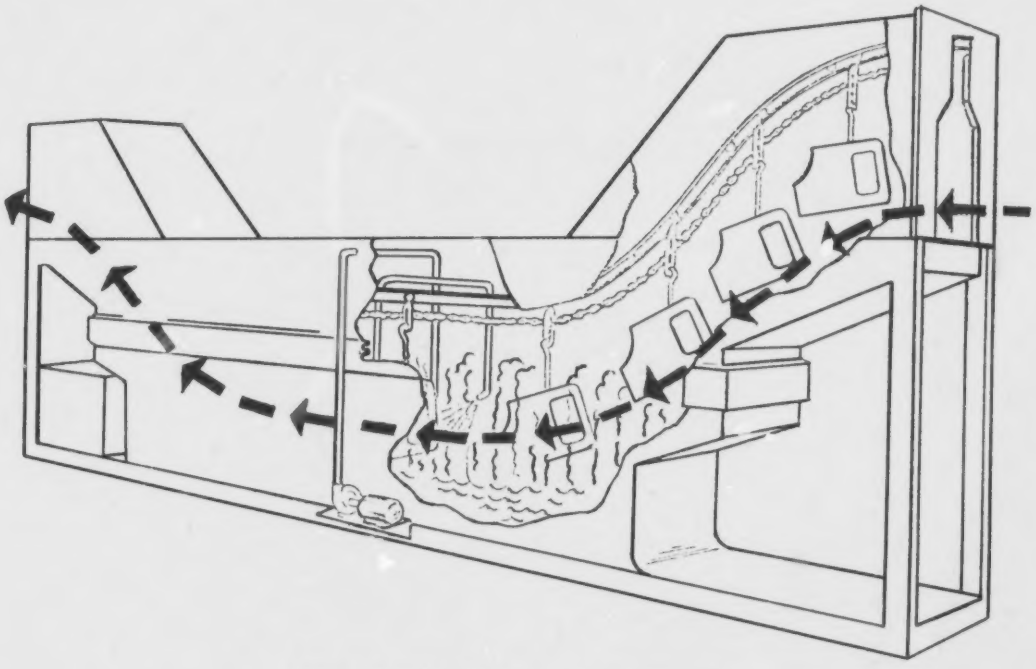


Figure 4. Monorail Conveyorized Degreaser

The advantages of solvent cleaning relative to water washing are:

- Vapor degreasing systems consume significantly less energy than water systems;
- Solvents are highly effective for removing soluble oils and greases and therefore less expensive;
- Solvent cleaning is usually more effective in cleaning precision parts and is safer for rust-sensitive metals; and
- Solvent cleaning is effective for small parts.

NON-SOLVENT CLEANING

There are many combinations of water-based solutions for cleaning and many methods of using them. Water-based solutions usually have a pH greater than 7.0 and thus are alkaline washing systems. Since water is cheaper than solvents, these are the first cleaning methods considered in figuring costs.

Water by itself cannot perform all necessary cleaning of metal parts. It must be assisted by mechanical action (agitation), cleaning compounds, and heat.

The washing action for alkaline systems may include soaking, spraying, tumbling, electrolytic action, flushing, and handwiping. These cycles can be housed within automated systems using moving belts, monorails, or spirals, or they can be carried out in open top tanks.

Cleaning compounds include caustics, carbonate salts, phosphates, silicates, borates, soaps, and surfactants. Concentrations of cleaning compounds in washers range from 0.5 to 12 ounces per gallon of water, but agitation reduces the concentrations required. The combination of cleaning compounds and mechanical agitation enables the following cleaning functions:

- Wetting—Loosening soil through use of an active agent that lessens surface tension of the metal;
- Emulsifying—Dispersing two immiscible liquids after wetting occurs, one usually an oil or grease;
- Saponification—Forming soap (which may then be removed by abrasives) by reaction of an organic oil containing fatty acids with free alkali;
- Deflocculation—Breaking the soil into fine particles that are dispersed in the cleaning media and prevented from agglomerating; and
- Sequestration—Tying up metal ions, such as calcium and magnesium, so that they cannot react with and precipitate oils.

Alkaline cleaning compounds can be liquids or solids; low-temperature cleaning to save energy often requires liquid compounds.

For alkaline washing of metal to be effective, the soils build-up in the cleaning solution must be limited, and rinsing, which can be done with clean alkaline solution, tap water, or deionized water, must be thorough. If the rinsing is not thorough, a soil residue will remain on the metal surface.

Drying is often necessary after alkaline washing to ready parts for the subsequent metal operation. Drying is not needed in vapor degreasing units where the metal part becomes hot enough to evaporate the solvent when it is withdrawn from the vapor zone.

The advantages of alkaline washing, relative to solvent degreasing, are:

- Alkaline solutions have a lower cost per gallon than solvents, especially the halogenated solvents. However, some of this cost advantage is offset by the lower tolerances of soils build-up in the cleaning solution, necessitating more frequent changes.
- Alkaline washing systems are compatible with subsequent operations that use wet processes like plating and phosphating. The energy cost of drying the parts is eliminated in these cases, although overall energy costs for alkaline washing are high.
- Alkaline systems are particularly effective in cleaning buffing compounds and solid dry lubricants whose soluble oils have volatilized. Chemical reactions, emulsifiers, agitation, and heat provide the cleaning action.
- Alkaline systems can tolerate more agitation and higher-pressure sprays for better cleaning. However, the additional agitation and higher-pressure spraying in solvent vapor degreasing disturbs the vapor zone and increases hydrocarbon emissions.

CHAPTER III

SOLVENT CLEANING EMISSIONS

The solvents used in solvent cleaning are one of many industrial sources of hydrocarbon emissions. Figure 5 shows the contribution of solvent cleaning emissions, broken down by vapor and cold cleaning, to annual hydrocarbon emissions in the United States. The figure also gives data for surface coating operations, related in many plants to solvent cleaning operations.

SOLVENT CLEANING EMISSION SOURCES

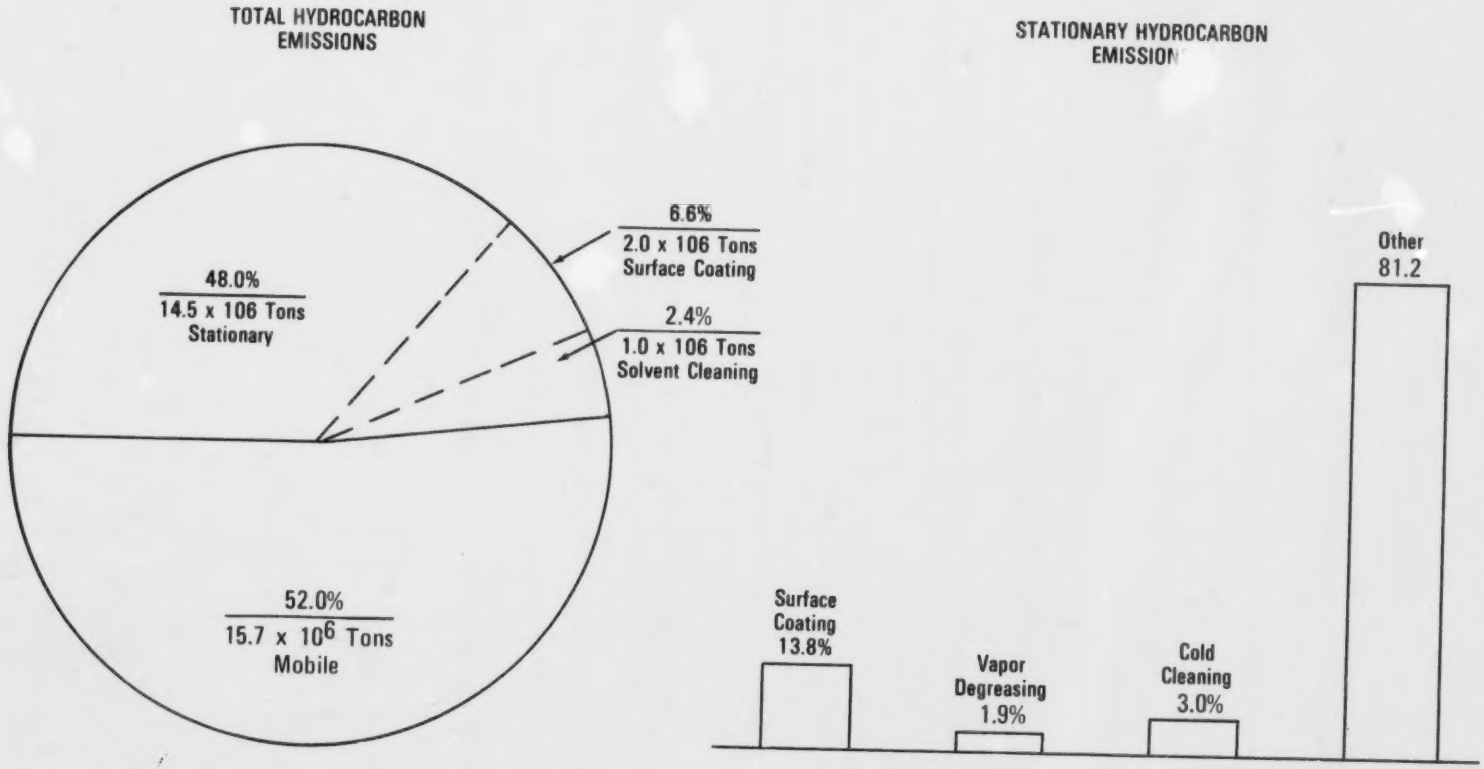
Solvent hydrocarbon emissions are caused by evaporation of the petroleum or halogenated solvents. Evaporation rates are a function of vapor pressure, which is directly proportional to temperature. At the temperatures prevailing in most plants, solvent vapor pressures are sufficient for evaporation. When evaporated solvent and a given volume of air mix, they each exert a partial pressure; at 20°C, the total atmospheric pressure is 760 mm of mercury. Solvent evaporation will occur until, at a given temperature, a maximum partial pressure is reached, a condition of equilibrium or saturation.

For example, trichloroethylene has a partial pressure of 60 mm mercury at 20°C. In a given volume of air, this solvent will evaporate until its partial pressure is reached. The volume it occupies is in the ratio of its partial pressure to air, $\frac{60}{760}$; or 7.9 percent of the total volume. This percentage of trichloroethylene in air would be 79,000 ppm at equilibrium. Because the TLV of trichloroethylene for worker exposure is 100 ppm, control or dilution is needed to offset the natural tendencies of this solvent to evaporate.

OPEN TOP TANK VAPOR DEGREASING

An earlier figure (Figure 1) depicting an open top vapor degreaser is here reproduced as Figure 6, and marked to show how hydrocarbon emission occurs.

Solvent is heated at the bottom of the tank by gas, electric, or steam coils. The heating coils may cover the entire degreaser bottom or be confined to a separate boiling chamber within the degreaser. The hot vapors generated are heavier than air and displace the air inside the degreaser tank. As boiling continues, the vapor volume increases. The bulk of the vapor is prevented from escaping the tank by condenser coils attached to one or more walls of the tank near the top. In small tanks, the coils might be at one end; in larger tanks, the coils may surround the entire tank. Open tank degreasers of all sizes usually have water jackets with flowing water around the entire tank (above the coils) for further condensing action.



Data Sources: TRC – The Research Corporation of New England and EPA Office of Air Quality Planning and Standards

Figure 5. Contribution of Solvent Metal Cleaning Hydrocarbon Emissions to Other Hydrocarbon Emissions, 1972

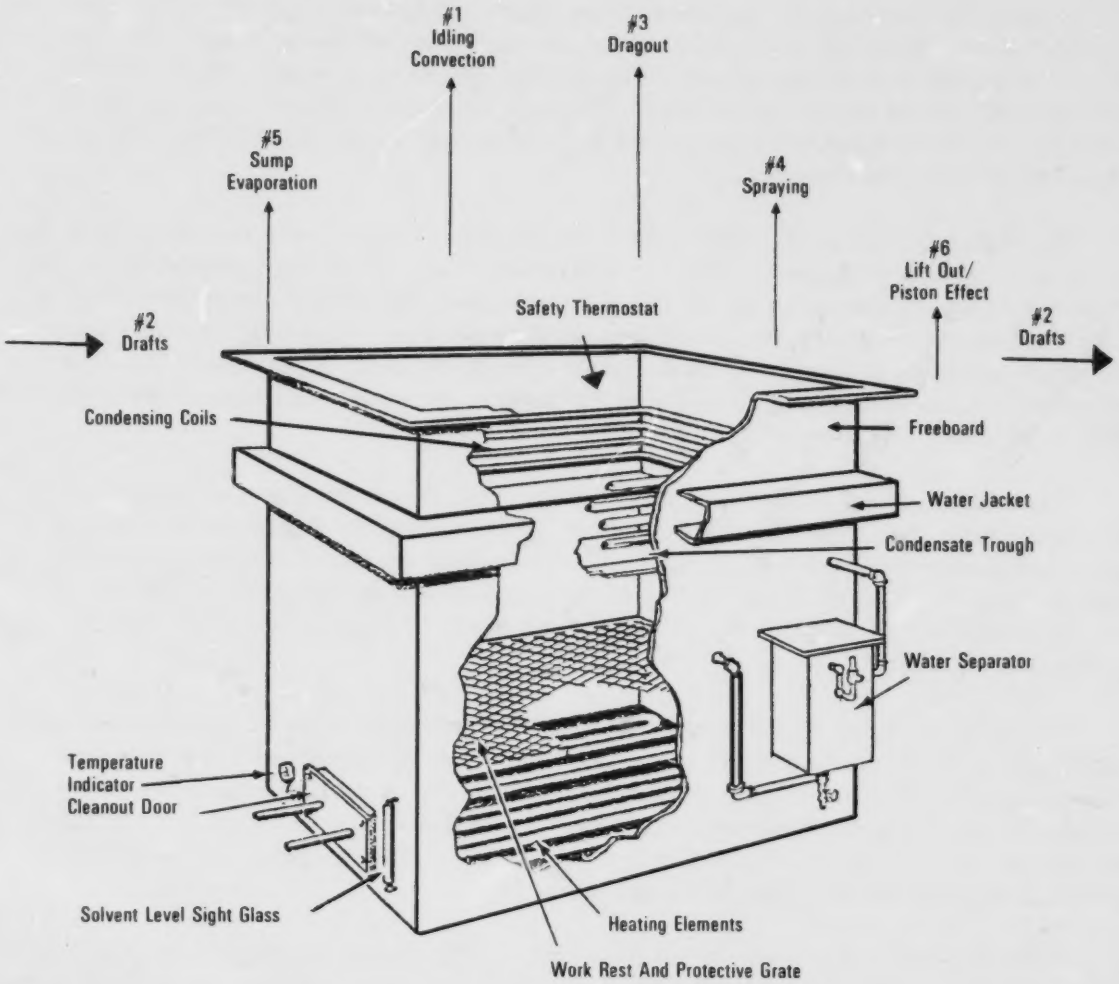


Figure 6. Emission Sources in Open Top Degreasers

Condensation of vapor on the condensing coils prevents further rise into the vapor zone when the degreaser heat-input and condenser heat-outflow are balanced. Even then, some solvent vapors will escape through diffusion of the uncondensed fraction.

Because the amount of a solvent vapor escaping depends on its partial pressure at the condenser temperature, one would expect different emission rates for the various solvents. However, the industry uses a general rule of thumb for the evaporation rate of all halogenated solvents—.05 lbs/ft^2/hr of open top area.

Above the condensing coils are additional degreaser walls, called freeboard, that protect the top of the vapor zone from being disturbed by drafts (Figure 6 - #2). Solvents are emitted when drafts cause air and solvent to mix at the top of the vapor zone. Denser vapors, such as trichlorotrifluoroethane (6.5 density, with air equal to 1.00) and perchloroethylene (5.73), are less disturbed by drafts than, for instance, methylene chloride, which has a density of only 2.93.

In open top degreasers, the object to be cleaned is lowered into the vapor zone. The hot vapor condenses on the cold metal, dissolves the soluble greases, and flows off. It is replaced by clean solvent. The solvent, greases, and soils return to the boiling liquid on the bottom of the tank. The high boiling points of the greases and soils prevent them from being vaporized and contaminating the solvent vapor zone, ensuring high-quality cleaning.

The metal is held in the vapor zone until the metal temperature reaches that of the vapor and condensation has stopped. A solvent film will, however, remain on the metal surface. When condensation on the metal has stopped, the part is slowly removed. As the object is removed, the heat of the metal evaporates the remaining solvent film. Where evaporation is completed in the upper zone of the tank, most of this solvent is recovered by the condensing coils and water jacket. Solvent evaporated outside the tank is termed "drag-out" (Figure 6 - #3).

Some tanks have hoses with nozzles for spraying the part while it is suspended in the vapor zone, which enhances the cleaning action. Separate chambers that collect uncontaminated solvent from the condenser water separators are frequently used to feed the sprayer. Some degreasers also have liquid solvent chambers where the part can be immersed for additional cleaning or immersed in the boiling solvent for cleaning by the boiling action.

Improper spraying can increase hydrocarbon emissions in two ways: Vapors created when spraying is performed above the vapor level will be subject to drafts and dispersion from the cleaning unit; spraying near the top of the vapor zone can cause relatively uncontaminated air from above the zone to mix with and force out contaminated zone air (Figure 6 - #4). Very fine sprays or aspirated sprays cause greater disturbance than low-pressure flush spraying.

When the vapor degreaser is not in operation, the solvent on the bottom will evaporate (Figure 6 - #5). Emissions will occur unless the top of the tank is covered during these shutdown times. If the surface area of the metals being lowered into the zone is greater than 50 percent of the open tank area, emissions will occur as the load is lowered and again when it is lifted out. Such emissions are referred to as piston-effect emissions, with the tank acting as the cylinder and the bulky load the piston.

The three most significant emission sources in open tank top vapor degreasing are those from:

- Drag-out;
- Solvent Disposal; and
- Improper Spraying.

CONVEYORIZED VAPOR DEGREASING

Conveyorized vapor degreasers are usually larger and more expensive than open tank degreasers and therefore fewer are normally used in a single plant. The cleaning

principles of conveyorized systems are the same as those for open top tank degreasers. The main difference between the two systems is in materials handling. Metal objects are transported through the liquid or vapor zone of closed systems by monorails, chains, mesh belts, or moving spiraling trays. Monorails are expedient where the parts move by monorail in other parts of the plant. Parts can be carried in baskets or in rotating perforated cylinders.

All conveyorized systems use either hot liquid immersion or solvent spraying, combined with movement of the part through a vapor zone. Drag-out air pollution occurs to a lesser degree than in open top systems because the conveyor speed can be regulated so that evaporation takes place in the enclosed system. Close-fitting enclosures at the degreaser entrance and exit decrease vapor loss from plant air movement. Piston-effect solvent emissions do not occur in conveyorized systems because the carrier size and spacing can be designed to avoid it. Some idling convection and sump evaporations occur, but not as much as in open top tanks.

Because the emission rate per unit of metal cleaned is lower than in open tanks, the use of closed conveyor systems can be considered as a control device.

COLD CLEANING

There have been relatively few cold cleaning conveyorized systems installed. The main difference in emissions between conveyorized vapor and conveyorized cold cleaning methods is the rate of drag-out, which occurs because the metal is not heated during cleaning and the solvent is not vaporized inside the closed system. An attempt can be made to dry the metals inside the conveyor by forced air or with ultraviolet light (printed circuit board cleaners), but forced air will increase cold cleaning emissions.

In addition to drag-out effects, cold cleaning tank emissions are the result of spray evaporation, surface evaporation, and draft-induced surface evaporation. Traditionally, it has been assumed that open-top cold cleaning produces more emissions than open top vapor degreasing. However, a set of recent tests at Presolite Corp. showed 47 percent fewer emissions when the tank was operated cold.

SOLVENT WASTE

Hydrocarbon emissions from disposal of spent solvents make up a significant portion of the nation's total solvent hydrocarbon emissions. Some solvent disposal methods are considered as part of air emissions because ultimately the solvent evaporates. These methods include flushing and landfilling, whether done by a manufacturer or a disposal service. Disposal of solvents through a reclaimer or by proper incineration are not methods that contribute to hydrocarbon air pollution.

Approximately 35 percent of all solvents used by plants with more than 19 employees require disposal. Half of the disposed amounts evaporate. Therefore, about one-sixth of yearly hydrocarbon emissions from these plants result from disposal practices. For plants with 19 employees or less, utilizing primarily cold cleaning systems, the residues are a higher percentage of total solvent use, and a lower percentage of solvent

is reclaimed. Therefore, the figure of one-sixth (disposal emissions as a fraction of solvent use) used above for plants of 20 or more employees increases significantly when smaller plants are included.

Calculations for compliance purposes frequently include disposed solvents as part of the plant's hydrocarbon emissions load. In jurisdictions where air pollution control regulations apply to solvent degreasers, emission limits are expressed in pounds per hour or pounds per 24-hour day. One method of determining the uncontrolled emission rate is through materials-balance calculations in which the amount of solvent fed to the degreaser over a period of time is recorded and not reduced by the amounts disposed of, unless these go to a reclaimer or are burned.

The economics of whether to sell spent solvent to a reclaimer or to develop on-site recovery will depend on the amount and type of solvent consumed. For the more expensive halogenated solvents, it will frequently be economical to reprocess the solvent on-site, using a small distillation unit. However, for the cheaper hydrocarbons, a high volume is necessary to justify on-site distillation. Further, with petroleum-derived solvents, measures must be taken against flammability.

In most industrialized areas, used solvents can be sold to specialty reclaiming firms. The income may be minor, but disposal problems are avoided. Only in remote areas, or in the case of small solvent volumes or badly contaminated or mixed solvents, should distillation or resale be ruled out.

Large degreasers are often equipped with their own attached stills for separating the solvent from the greases and soils. Separate stills can be centrally located in a plant to reclaim solvents from several degreasers.

Open top degreasers without separate stills collect some solvent condensate in troughs under the condensing coils, and contamination concentration in the disposed solvent can be increased in this way to 20-40 percent. Stills can recover enough solvent vapor from used solvents to increase the soil and grease concentration to 60-85 percent before final disposal of the solvent. Specially designed stills may leave only 5 percent solvent in the residue.

Properly designed stills can be operated without emitting their own air pollution.

COMPARISONS OF SOLVENT CLEANING SYSTEMS EMISSIONS

There is no survey that thoroughly compares hydrocarbon emission rates for various solvent cleaning systems, probably because of the difficulty of finding representative systems that clean the same types of parts. The information available, however, suggests the following ranking of solvent metal cleaning options by emission rates, from lowest to highest, considering equivalent wasteloads:

1. Conveyorized vapor degreasing
2. Conveyorized cold cleaning

3. Open top vapor degreasing

4. Open top cold cleaning with petroleum solvents

5. Open top cold cleaning with halogenated solvents.

Exceptions to this ranking are easily found. Further, we are not suggesting that the systems are interchangeable and that a plant could reduce emissions or achieve compliance by switching to a higher-ranked, lower-emission system. Other factors (discussed in Chapter II) would first have to be evaluated, including characteristic differences between petroleum and halogenated solvents, large and small volumes, and open top and conveyorized systems. The effectiveness of vapor exposure vs. dipping in partially contaminated liquids would also have to be considered. The overall findings might well preclude switching.

The reasons that conveyorized systems using halogenated solvents (vapor or cold) cause fewer emissions than open top systems are:

- Elimination of losses from plant air movements;
- Capturing of more drag-out evaporation by the enclosure;
- Greater efficiency of automation and high-production operations in solvent use; and
- Reduction of waste solvent at the source, with distilling systems often built into the larger conveyorized systems.

The primary reason that conveyorized vapor systems cause fewer emissions than conveyorized cold systems is less drag-out. The unheated metal in a cold system means that more solvent evaporation occurs outside the enclosure than in vapor systems. As noted earlier, if forced air drying is used inside the enclosure to reduce cold-system drag-out, the disturbance could increase exhaust emissions and would tend to offset any decrease in drag-out.

One report describes two cases where similar parts were being vapor-degreased by an open top tank at one plant and by a conveyorized cross-rod system at another. Very careful production and solvent consumption records were kept at each plant. The solvent consumption per ton of metal cleaned in the open top tank was 99 pounds using trichloroethylene, and 80 pounds using 1,1,1-trichloroethane. The solvent consumption rate in the conveyorized system using trichloroethylene was 35 pounds with carbon adsorption and was estimated at 44 pounds without the adsorption system.[1]

Another case involved replacement of an open top tank vapor degreaser with a partially enclosed conveyorized vapor degreaser equipped with a still. Emissions per weight of metal cleaned were 40 percent less with the partially enclosed system. Doubling the production load for metal cleaning facilitated the decision to switch to the more expensive conveyorized system.[1]

There are fewer emissions with open-top vapor degreasing than open top cold cleaning, with either halogenated or petroleum solvents. The primary reasons are:

- The use of condensation systems (water jackets, cooling coils using water, or refrigerated coils) to prevent solvent emissions; and
- The reduction of drag-out emissions because the heated metal causes condensate evaporation in the vapor zone.

There are other equipment and operating factors that cause higher emissions from cold cleaning systems. These include:

- Frequent use of mechanical agitation (spraying, air agitation, and mixers) to improve cleaning, which increases the evaporation of solvents;
- Lower soil concentration tolerances in cold cleaning (5-10 percent for cold cleaning vs. 15-25 percent for vapor degreasing), which increase the need for distillation or disposal;[1] and
- The difficulties and cost of distilling petroleum solvents, which make emission rates dependent on how a plant disposes of its waste solvent.

On the other hand, petroleum solvents themselves cause fewer emissions than halogenated hydrocarbons. The difference in evaporation rates is shown below:

	Relative Evaporation Rates[1] (1,1,1-trichloroethane = 1.00)
Stoddard	.09
Perchloroethylene	.25
Heptane	.40
Trichloroethylene	.63
1,1,1-trichloroethane	1.00
Acetone	1.40
Methylene Chloride	3.50
Trichlorotrifluoroethane	3.85

However, benefits from the lower emission rates of petroleum solvents are dependent upon disposal practices. Because of the flammability problem previously described, petroleum distillation is very expensive, and any disposal practice leading to evaporation will significantly increase the emission calculations.

EMISSION RATES

There are essentially two ways to quantify emissions:

- Concentration (weight or volume) of solvent in the air emitted from the degreaser; and
- Solvent consumed by the degreaser over a time period (materials-balance data).

The first method is useful for the design of a vapor recovery system such as carbon adsorption. However, concentration measurements are not valid for determining compliance with air pollution control regulations, because even though concentrations can readily be converted to pounds per hour (to conform to typical regulatory specifications), this does not account for solvent disposal, sump evaporation and leakage losses. Therefore, solvent consumed by the degreaser is a more accurate measure for compliance-determination purposes.

The common solvent consumption measurement consists simply of recording all solvent added to the solvent cleaning system to maintain a constant level and dividing this by system-operating hours. This yields an average emission in pounds per hour and includes all solvent losses. Because of errors in determining the liquid levels when adding solvent, it is preferable to develop materials-balance data over several weeks or months. For a more precise measurement, the degree of contamination of the solvent in the degreaser at the last addition must also be known. Because the grease generally has a higher boiling point than the solvent, an estimate of the grease content can be obtained by evaporating a known quantity of the dirty solvent in a weighted dish to determine the weight of solvent loss.

A sample materials-balance calculation is given below:

Given: A vapor degreaser of 4 ft x 5 ft surface dimensions with a liquid depth of 2 ft. The solvent used is trichloroethylene. The degreaser is used 7 hours per day on a 5-day per week basis and is covered at other times.

Procedure:

1. Clean the degreaser and fill to the 2-ft level with trichloroethylene.
2. Maintain records on additions of makeup solvent over a selected period of time, e.g., 4 weeks. For calculation purposes, assume that additions of 5, 6, 5, 8, 7, 6, 5, and 4 gallons were added to the degreaser during the 20 operating days.
3. At the end of the 4-week period, carefully make up the solvent level to a 2-ft depth. Assume that an additional 2.5 gallons was required for this purpose.
4. Collect a suitably sized sample of the degreaser solution and place in a dish in a drying oven at a temperature slightly below the boiling point of trichloroethylene. Assume that a 100 ml sample is used. The

sample and dish weigh 212.4 gm. After drying at 175°F to remove the solvent, the cooled dish and contents weigh 88.7 gm.

Calculations:

1. Total solvent added from steps 2 and 3 above = 5 + 6 + 5 + 8 + 7 + 6 + 5 + 4 + 2.5 gallons = 48.5 gallons.

2. Solvent displaced by grease =

$$\left(1 - \frac{\text{Volume solvent evaporated, ml}}{100\,\text{ml}}\right) \times \text{Volume of Solvent in degreaser}$$

   - Weight loss in dish

     = 212.4 gm - 88.7 gm

     = 123.7 gm

   - Volume less

     $$= \frac{123.7\,\text{gm}}{1.456\,\text{gm/ml}}$$

     = 85.0 ml

   - Volume of solvent in degreaser

     $= 4\,\text{ft} \times 5\,\text{ft} \times 2\,\text{ft} \times 7.48\,\text{gal/ft}^3$

     = 299.2 gal

   - Thus, solvent displaced

     $$= \left(1 - \frac{85.0\,\text{ml}}{100\,\text{ml}}\right) \times 299.2$$

     = 44.9 gallons

3. Emission rate $= \dfrac{\text{Total Solvent Loss (in lbs)}}{\text{Operating Hours}}$

$$= \frac{(48.5\,\text{gals} + 44.9\,\text{gals}) \times (1.456 \times 8.34\,\text{lb/gal})}{4\ \text{weeks} \times 5\ \text{days} \times 7\ \text{hrs/day}}$$

$$= 8.1\,\text{lbs/operating hour}$$

$$= 56.7\,\text{lbs/day}$$

The result represents the total diffusion, convection, and drag-out losses during [illegible] week period. The only error would result from solvent displacement in the tank by the accumulation of solid soil (metal chips, dirt, etc.), and possibly from water in the degreaser. These materials would not mix with the solvent and would not be present in the selected sample used for drying. If these factors are significant, it would be necessary to drain the tank and obtain an estimate of the volume of water and soil at the end of the test period. This volume of additional contaminants would then be added to the other solvent losses in step 3 of the calculation above.

A materials-balance calculation stated in weight per unit of time is useful in meeting regulatory requirements, but not for the design of vapor recovery systems such as carbon adsorption. The concentration of inlet gases to a carbon adsorption system is a critical design factor. Materials-balance figures, although mathematically convertible to concentrations, would not yield an accurate inlet concentration. The converted figures would be too high because they include drag-out losses, waste-solvent disposal, and shutdown evaporation. None of these emission sources would be ventilated to a carbon bed.

Some emission data are available for solvent cleaning operations, derived from materials-balance calculations and expressed in concentrations of ppm or in pounds per hour. Rule-of-thumb emission rates, derived from materials-balance calculations for open top tank vapor degreasers, are from .25 - .50 lbs/hr/ft^2 of open top tank area. (The rule of thumb for convection losses during idling is .05 lbs/hr/ft^2, or 10 - 20 percent of the total emission rates.[6]) Since applicable regulations usually allow 8 pounds of emissions per hour, the estimated tank size for regulated emissions cannot exceed 16 ft^2 or 32 ft^2. These calculations and emission rates include assumptions that:

- The tank is covered at all times during shutdown;
- Condensing coils and a water jacket are used; and
- The vapor degreaser has minimal freeboard.

Again, it must be remembered that materials-balance emission rates represent an average per hour. They do not reflect either peak concentration during heavy workloads or concentrations that leave through the degreaser opening.

No rule-of-thumb emission rates have been established for conveyorized solvent cleaning systems.

SOLVENT VAPOR CONCENTRATIONS

Concentrations from the solvent cleaning openings have been found to vary from 50 ppm to 1000 ppm, the low end of the range occurring during idling and the high end during cleaning.[1]

At present, there is no federal government reference on sampling hydrocarbon solvent concentrations and no preferred method. There are, however, methods for measuring sample concentrations of halogenated solvents. These sampling methods can measure the ventilated air from a solvent cleaner or the breakthrough point of a carbon adsorption system, i.e., the jump in emissions after the bed is saturated.

Available sampling equipment can measure general organic compounds or specific compounds. Some systems provide on-site results; others require remote laboratory analysis. Gas chromotography is one on-site sampling system for specific organic compounds. The cost and maintenance of gas chromotography facilities is high for small plants, but it is possible for air samples to be taken and analyzed by this method at an outside laboratory.

For air pollution purposes, the need for sampling specific compounds is minimal; the more useful measure is total organic concentrations. Direct-reading, on-site total organic sampling systems are available, based on coulometry, ionization, thermal conductivity, combustion, ultraviolet and IR spectroscopy, chemiluminescence, electric conductivity, or flame photometry.

Most suppliers of solvents and carbon adsorption systems have technicians who can perform all emission measurements for customers, and where multiple adsorption beds are used, suppliers can also design the carbon bed switching systems. Switching is typically accomplished by timers. When the beds are first installed, the supplier measures the time to breakthrough, applies a safety factor, and establishes an automatic timing cycle.

SOLVENT VENTILATION SYSTEMS

Ventilation of solvent cleaners is often necessary to carry vapors away from workers and plant equipment. It is also important where the effectiveness of various controls depends on solvent vapor concentrations.

However, excessive ventilation increases the solvent loss rate. The objective is to attain only that ventilation rate commensurate with worker safety and plant equipment protection.

Where worker safety is not involved, the desired ventilation rate from a vapor degreaser is a maximum of 50 cfm/ft^2 of opening. As ventilation rates increase from this level, so does solvent vapor loss. In some cases, worker safety requirements may call for a minimum ventilation rate of 100 cfm/ft^2 of opening. At this rate, there is significant impairment of the various emission reduction techniques (to be described later) that can be used inside the degreaser.

Conventional open top vapor degreasers have a lip or slot ventilation arrangement running laterally along the top of the degreaser below the freeboard. However, this is not always sufficient to keep the room air solvent concentrations at safe levels, and it may be necessary to enclose the entire cleaning and drying area.

For conveyorized systems, a centrally located air intake can be used, at the recommended ventilation rate of 75 cfm/ft^2 of inlet and outlet openings. When drag-out losses are high from conveyorized systems, a grille top downdraft hood can be used. The recommended exhaust rate is 100 cfm/ft^2 of grille top.

In some cases, filters should be used with the ventilation system to remove dust generated by other operations in the plant. The filters will prevent adsorption-type recovery systems from clogging.

APPLICABLE REGULATIONS

Air pollution regulations specifically affecting solvent cleaning operations are under dual regulatory control: state authority sets the rules and standards for existing solvent cleaning operations and the EPA is responsible for establishing rules and criteria for emissions from new sources of pollution and modified solvent cleaning systems.

EXISTING SOURCES

As of June 30, 1976, there were air pollution control regulations for hydrocarbons in 22 states, although some regulations cover only a local area. Only three states have specific regulations for solvent operations, and in each case these are local: Arizona (for Maricopa County); California (for Los Angeles, San Diego, Sacramento Valley, San Joaquin Valley, and San Francisco); and Texas (for Houston-Galveston). In all other regulations, solvent cleaning operations are affected as a part of the hydrocarbon or surface coating category.

There are two types of applicable regulations, specifying:

- Allowable pounds per hour; or
- Allowable pounds per hour as a function of a designated photochemical reactivity of the solvent.

The pounds-per-hour limits, as expressed in Appendix B of the August 14, 1976 Federal Register guidelines and criteria for the adoption of State Implementation Plans, were no more than 3 pounds per hour or 15 pounds per day, unless 85-percent controlled. Common solvents used in vapor degreasers, except trichloroethylene, were exempted from this regulation. Therefore, plants affected by these regulations switched from trichloroethylene, often to 1,1,1-trichloroethane.

The second type of regulation is exemplified by the benchmark "Rule 66" of Los Angeles County Air Pollution Control District (later to become Southern California Air Pollution Control District Rule 442) which states: "For the purpose of this rule, a photochemically reactive solvent is any solvent with an aggregate of more than 20 percent of its total volume composed of the chemical compounds classified below, or, which exceeds any of the individual percentage composition limitations referred to the total volume of solvent:

(1) A combination of hydrocarbons, alcohols, aldehydes, esters, ethers or ketones, having an olefinic or cycloolefinic type of unsaturation: 5 percent;

(2) A combination of aromatic compounds with eight or more carbon atoms to the molecule except ethyl-benzene: 8 percent;

(3) A combination of ethyl-benzene, ketones having branched hydrocarbon structures, trichloroethylene, or toluene: 20 percent."

Rule 66 (now Rule 442) bases its emission regulations on this designated photochemical reactivity. The Rule states:

"(a) A person shall not discharge organic materials into the atmosphere from equipment in which organic solvents or materials containing organic solvents are used, unless such emissions have been reduced by at least 85% or to the following:

(1) Organic materials that come into contact with flame or are baked, heat cured or heat polymerized, are limited to 1.4 kilograms (3.1 pounds) per hour not to exceed 6.5 kilograms (14.3 pounds) per day.

(2) Organic material emitted into the atmosphere from the use of photochemically reactive solvents are limited to 3.6 kilograms (7.9 pounds) per hour, not to exceed 18 kilograms (39.6 pounds) per day, except as provided in subsection (a) (1). All organic materials emitted for a drying period of 12 hours following their application shall be included in this limit.

(3) Organic materials emitted into the atmosphere from the use of non-photochemically reactive solvents are limited to 180 kilograms (396 pounds) per hour not to exceed 1360 kilograms (2970 pounds) per day, except as provided in subsection (a) (1). All organic materials emitted for a drying period of 12 hours following their application shall be included in this limit.

(b) (omitted here because it is not germane to solvent cleaning.)

(c) Emissions of organic materials into the atmosphere required to be controlled by subsection (a) shall be reduced by:

(1) Incineration, provided that 90 percent or more of the carbon in the organic material being incinerated is oxidized to non-organic materials or

(2) Incineration, provided that the concentration of organic material following incineration is less than 50 ppm, calculated as carbon and with no dilution, or

(3) Adsorption, or

(4) Processing in a manner determined by the Air Pollution Control Officer to be not less effective than (1) or (3) above."[7]

The rule also specifies an allowable disposal of no more than 1.5 gallons per day of reactive solvent.

Any regulated solvent cleaning emission source that cannot be exempted by substituting compliance solvents constitutes a serious control problem. Data in Chapters IV and V indicate that the effectiveness of emission reduction and control systems for solvent cleaning ranges up to 60 percent. Even though a device like carbon adsorption is over 90 percent effective, it cannot control the substantial drag-out solvent waste and sump evaporation losses that escape the ventilation systems.

Therefore, the maximum controllable emission rate any source can have is approximately 20 pounds per hour (8 ÷ (1 - .60)).

Within the next few years, it is anticipated that more existing hydrocarbon sources, including solvent metal cleaning, will be required to reduce solvent consumption and/or emissions. Many states have not achieved the primary air quality standard for photochemical oxidants, the air pollutants related to hydrocarbons. EPA has required these states to change their implementation plans to achieve more control of hydrocarbon sources. States have discretion in choosing which sources they want to control, i.e., mobile vs. stationary, refineries vs. surface coating, etc.

EPA will be issuing guidelines to the states on reasonably available control technology for solvent metal cleaning. These guidelines can be used by the states that must change their implementation plans to include existing solvent metal cleaning sources.

NEW SOURCES

The Environmental Protection Agency is now considering regulating all new solvent cleaning systems; these regulations are known as New Source Performance Standards (NSPS). A new source can be either a new system or a modified existing degreaser costing more than 50 percent of a new source. Increases in emissions from an existing source due to fuel conversion or increases in production rates or operating hours are not, in most cases, governed by NSPS.

NSPS regulations call for new sources to install the best available control technology. The standards are usually industry-specific and are generally expressed in performance terms such as weight per standard cubic foot of air flow per minute. This gives maximum engineering options to the plant engineer. Where standards are design-specific, such as to height of freeboard vs. width of tank or temperature of refrigerated chillers, the control options are limited. The NSPS, though still under consideration by EPA and not yet finalized, may use design-specific standards because of the difficulty of measuring concentrations and the extensive record keeping involved in material balances, and because controlled emission rates vary greatly according to the amount and type of wasteloads.

CHAPTER IV

PROCESS CHANGES FOR REDUCING SOLVENT CLEANING EMISSIONS

Techniques for reducing solvent emissions from solvent cleaning operations (referred to as process changes) include:

- Cleaning changes;
- Solvent substitutions;
- Solvent degreasing equipment substitutions;
- Solvent degreasing equipment modifications;
- Solvent degreasing operating improvements;
- Distillation or reclamation; and
- Combinations of process changes.

CLEANING CHANGES

Water-based and solvent-based metal cleaning methods are theoretically interchangeable. However, the soil or grease to be removed, the type of metal, and the ensuing operations often dictate the choice of cleaning.

For many applications, for instance, water-based methods are uneconomical because of the rinsing and drying operations they necessitate. However, when air pollution control costs are added to the equation, a reassessment may be necessary, based on a comparison of the added cost of water pollution control with the cost of controlling air pollution from solvent cleaning.

SOLVENT SUBSTITUTIONS

In some instances, compliance with present state hydrocarbon pollution control regulations can still be met through solvent substitutions. For vapor degreasing, this virtually always means replacing trichloroethylene with 1,1,1-trichloroethane, perchloroethylene, methylene chloride, or trichlorotrifluoroethane.

Trichloroethylene is considered by the Los Angeles Air Pollution Control District and the Environmental Protection Agency to be a reactive pollutant. Regulations enacted to date exempt all other halogenated solvents in common use as nonphotochemically reactive. More-recent information from the Environmental Protection Agency indicates further refinements in the designations.

Trichloroethylene and the petroleum solvents have moderate photochemical reactivity in the short run, usually considered one day. Perchloroethylene is relatively unreactive the first day, but significantly reactive beyond that. Methylene chloride, 1,1,1-trichloroethane, and trichlorotrifluoroethane are considered unreactive.

Although solvent substitution is a widely accepted method of meeting regulations for existing sources, it is too early to predict what EPA may allow for New Source Performance Standards. EPA has several alternative control measures for NSPS for solvent cleaning operations, including both solvent substitution and equipment changes. While solvent substitution has traditionally been considered a good control strategy, there is some evidence that suggests otherwise. A recent EPA report states that solvent cleaning equipment and operating changes may be required with solvent substitutions.[2] For example, when methylene chloride or trichlorotrifluoroethane are substituted, the freeboard ratio must be increased to .75. Further, these solvents require less heat to vaporize, but more coolant is required to condense the vapors.

SOLVENT DEGREASING EQUIPMENT SUBSTITUTIONS

Chapter III compared the relative emission rates from various solvent cleaning operations and noted that conveyorized systems emitted fewer solvent vapors than open top tank systems for the same workload. Further, vapor degreasing in conveyorized systems caused fewer emissions than cold cleaning, which was also generally true for open top tank systems.

It may be worthwhile to substitute a conveyorized system for two or more open top tank degreasers. Because there are fundamental differences in cleaning quality between vapor degreasing and cold cleaning, cleaning specifications and solution soils concentration tolerances are critical considerations in any change from vapor to cold cleaning, in either an open top tank or in a conveyorized system.

AUTOMATIC OR MANUALLY OPERATED COVERS

This discussion applies to open top tank vapor or cold cleaning equipment only.

Actual metal cleaning takes place during only about 25 percent of a working shift. It is typical, even though covers come with the equipment, for open top systems to be left open during the extensive idling and shutdown time.

It is economical to cover tanks when they are not in use. Covers may be canvas, plastic, fiberglass, or metal and can be supplied by solvent cleaning equipment manufacturers. For large tanks, pedal-activated covers can be used. Automatic covers can also be equipped with timers that close them after a degreasing cycle. If non-horizontal covers are considered, precaution should be taken that the vapor zone is not disturbed by air movements. All covers should function below the lip exhaust.

Covers are highly effective, particularly during idling time, when emission rates are anywhere from .05 to .10 lbs/ft^2/hr; with covers, nearly all emissions can be prevented. Covers are even more necessary where freeboard height is minimal and where drafts exist, making idling emission as high as .37 lbs/ft^2/hr.

Tests that measured the effectiveness of covers on halogenated solvent consumption rates showed savings ranging from 24 to 50 percent.[1] The same equipment and solvents were used in the comparisons; the cover was the only variable.

The cost of covers is dependent on square footage. For retrofit situations and for automatic covers, the costs range from $100/ft^2 for 15 ft^2 to $25/ft^2 for 200 ft^2.

For a 4' x 12' open top system, the solvent emission savings with halogenated solvents should pay for the covers in 6 months for a three-shift operation, or in about 15 months for a single-shift operation. For cold cleaning in an open tank, the payback will take slightly longer.

For a 2 1/2' x 6' open top system, the payback period would range from 13 months to 2 1/2 years. Thus, covers appear to be an attractive investment even without the consideration of air pollution.

Where a plant already has covers for its tanks that employees fail to use properly, an automatic feature may help. Clearly marked instructions will also help the plant achieve the full emissions control benefits of covers.

If a cover cannot be used, for example over the weekends, it is recommended that the solvent be pumped out, stored, and re-entered at the next working shift.

INCREASED FREEBOARD

Greater freeboard height will reduce solvent emissions from open top tanks performing either vapor degreasing or cold cleaning. The current Occupational Safety and Health Act requires the freeboard height to be .50 times the width of the tank, but it need not be higher than 36". This ratio applies to the use of all solvents. It has been the practice of the industry, however, to have a ratio of .75 with methylene chloride and trichlorotrifluoroethane.

Increases above this height can further reduce solvent emissions. In addition to blocking drafts, the added height also permits the lip exhaust ventilation rates to be less disruptive to the vapor zone. In one set of tests, increasing the freeboard ratio from .50 to .75 of the tank width reduced solvent consumption by 27 percent.[1] With slight drafts occurring, the effectiveness in the same tests was 55 percent. Further ratio increases to 1.00 did not improve emission reduction efficiencies. Efficiencies for methylene chloride and trichlorotrifluoroethane would only improve if freeboard were increased above .75, the ratio in common use; however, no tests were run on this.

The current ASTM recommendation is a freeboard ratio for all solvents of .75, to a maximum 48"; the EPA's recommendation for new sources is expected to be about the same.

Increases in freeboard can easily be made by plant personnel or degreaser equipment manufacturers. However, increased heights can pose an operational problem because they may reduce materials handling space. For adequate handling, a pit may have to be dug to lower the degreaser. Increased freeboard may also require that the standing area around the degreaser be raised to enable operating personnel to handle the material or to spray. Spray hoses may require lengthening for spraying in the vapor zone.

The payback period for increasing freeboard from .50 to .75, or to a maximum of 48", should be less than one year, excluding any pit or worker-platform costs. Savings with cold cleaning open top equipment, where the freeboard has traditionally been smaller, should also be considerable.

REFRIGERATED CHILLERS

One method of controlling solvent emissions from vapor degreasers is to create a cold air blanket over the vapor zone that inhibits the vapor from rising. The blanket is created by a second set of condensing coils above the traditional condensing coils and water jacket. The added condensers, referred to as refrigerated chillers, are generally made of copper and are finned to obtain more contact area. Figure 7 shows a chiller and the effect it creates. A refrigerated chiller patent operates from 32°F down to -20°F. Other refrigerated chillers are operated outside the patent coverage, at temperatures of 34°F - 40°F.

When methylene chloride or trichlorotrifluoroethane is used, the condensing coils are operated at a 40°F-50°F temperature range and can be cooled by chilled water, possibly from a well. Degreaser equipment manufactures and other suppliers sell refrigerated chillers. Chillers operating below 32°F (The Cold Trap Model) have a removal capacity of 100 Btu/ft/hr per coil. Because two parallel coils are typical, the total removal capacity is 200 Btu/ft/hr. The above-freezing-temperature refrigerated chillers have total removal capacities of up to 500 Btu/ft/hr. New York State requires that the blanket temperature be 70 percent lower than the boiling point of the degreasing solvent and that the refrigerant temperature not be warmer than 0°F.[5] The energy requirement of chillers is only about 5 percent more than the vapor degreaser energy requirement.

One problem encountered with refrigerated chillers is frost on the coils. During the defrost cycle, water can enter the vapor zone; when this happens, it depletes solvent stabilizers and may corrode equipment. Degreasers using refrigerated chillers should be equipped with water separators, not shown in Figure 7. Water that collects on refrigerated chillers will extract the alcohol and acetone co-solvents from trichlorotrifluoroethane.

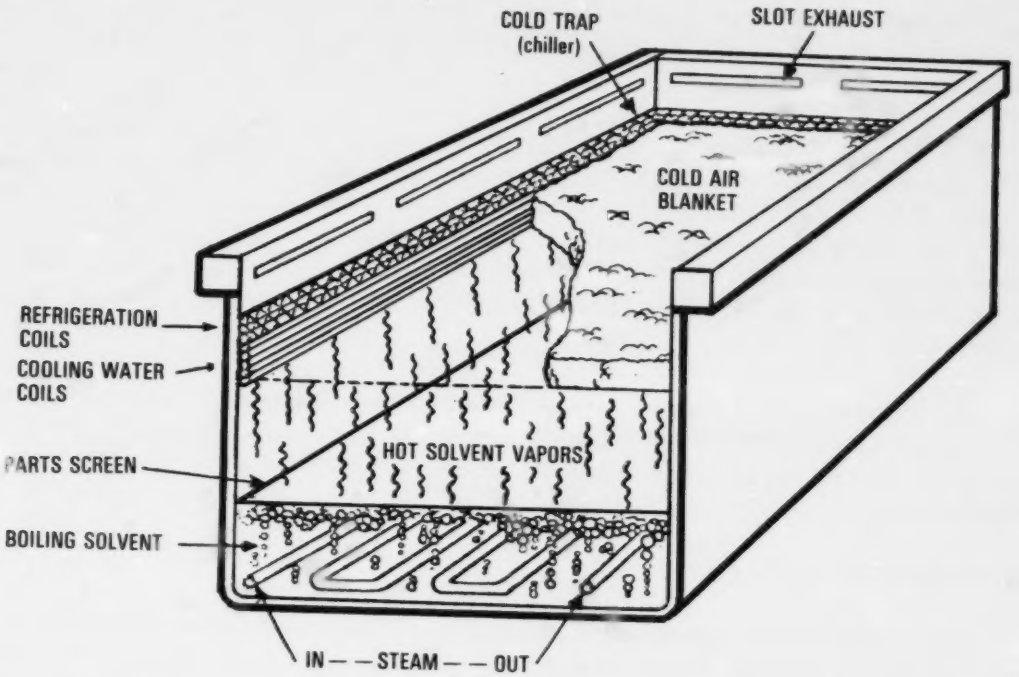


Figure 7. Schematic Representation of Degreaser with Cold Trap Installed[3]

One set of chiller tests showed an emission reduction range of 16-60 percent with an average of 40 percent.[1] Cost recovery, as expected, was better for multiple-shift operations and for the higher-priced halogenated solvents. Large and/or square vapor degreasers showed greater savings than small or narrow units.

Eight other chiller tests reported emission reduction ranges of 38-77 percent, with an average of 57 percent. These tests were not, however, verified by experimental control.

The actual payback periods for chillers vary considerably and are generally longer than those for covers and increased freeboard. Although the emission-reduction effectiveness of all three equipment modifications is similar, refrigerated chillers are the most expensive. The payback periods when trichloroethylene was used ranged from a loss for a one-shift operation using a low horsepower compressor to a payback of 2 years for a three-shift operation. Possible corrosion costs were not part of these payback calculations. The payback periods were shorter when the more expensive trichlorotrifluoroethane was used. No tests were made with cold cleaning operations, but significant control effectiveness can be expected with volatile solvents.

Refrigeration in primary condensing coils is a variation of the chiller concept. No test data is available on this process, and the costs are very high. As previously noted, condensing coils are standard equipment with methylene chloride and trichlorotrifluoroethane solvents.

The lip exhaust of the degreaser should have a shut-off device to prevent disturbing the cold air blanket when the chiller is operating.

DRAINAGE BOARDS

Drag-out from cold cleaning operations may contribute to dripping outside the tank. Solvent emissions can be prevented by catching the drippings with boards that drain back into the degreaser. No tests are reported for the emission reduction and cost effectiveness of this equipment modification.

SOLVENT DEGREASING OPERATING IMPROVEMENTS

The following suggestions have been presented by people in the metal cleaning field as practical, cost-effective means of reducing hydrocarbon emissions:

- Ventilation rates on all systems should be kept as low as possible, commensurate with health considerations (See OSHA).
- Parts should not be moved either vertically or horizontally through the vapor zone at speeds greater than 11 fpm (3.3 meters per minute).
- All solvent spraying should be performed in the vapor zone with low nozzle pressures (less than 10 psig).
- If a solvent spray cold cleaning method is used, the stream should be solid, that is, a flush, at a pressure not to exceed 10 psig.
- The opening(s) to closed conveyorized systems should not have more than 6 inches of space around the metals.
- Metal parts should be arranged in baskets and on hooks to avoid solvent puddles and assure that solvent does not drain from one part onto another.
- Where wipe-cleaning is the only way of cleaning, rags should not be allowed to drip and should be wrung or centrifuged after use.
- Cold cleaning containers and solvent spray reservoir temperatures should be at least 30°F-36°F less than the boiling point of the solvent, and in all cases no greater than 120°F, to avoid excessive evaporation.
- Cold cleaning solvent agitation should not be done with air when low-boiling-point solvents are used; mixers or recirculating pumps should be used instead.
- Routine inspections should be made for leaks.
- In cold cleaning systems where the solvent is immiscible with water and considerably denser, a 4" (10 cm) water seal can be used.
- Porous or adsorbent materials, such as cloth or rope, must not be cleaned or be part of the hoist or basket systems.
- The EPA suggests that the metal parts (the workload) should not occupy an area greater than 50 percent of top tank areas, to avoid piston effects, and ASTM suggests 75 percent.

- All vapor degreasers should be equipped with a safety-vapor thermostat that detects vapor rises and shuts off the sump heat source.
- Controls should also be used in vapor degreasers to prevent the primary coolant from overheating.
- Fans elsewhere in the plant should not be directed at a degreaser opening.
- Heavy loads with large surface areas should not stay too long in the freeboard area, since strong thermal updrafts from the hot work will draw vapors from below and emit them.
- All operators should be thoroughly familiar with all ways of reducing emissions, and reminder signs or labels should be posted where appropriate.
- Proper solvent cleaning start-up, shutdown, and maintenance procedures, as specified by ASTM,[5] should be followed.

Although no quantitative data is available on the effectiveness of these measures, they are highly recommended by those who have implemented them.

DISTILLATION OR RECLAMATION

For cold cleaning operations, perhaps the single most important process change to control emissions is solvent recovery, either by distillation at the plant or reclamation by a contractor. Distillation is also an effective emission control for vapor degreasing operations, though control is less important because waste volumes are lower in vapor systems.

Distillation is commonly used in plants that have closed conveyorized systems and many open top tanks, but not in those with one or two open top tank vapor degreasers or in petroleum-based cold cleaning systems. The options are single continuous stills connected to conveyorized units, continuous-feed centralized stills serving many degreasers, and separate batch stills.

Manufacturers sell long-lasting, stainless-steel stills with a capacity of 60 gallons per hour at a cost of $2500-$3500.[1] These units take up little floor space. Cost computations based on trichloroethylene show that a break-even figure can be obtained by a plant that distills 350 gallons per year. For petroleum-based solvents, the break-even point is from 2100 to 4200 gallons per year. Two major obstacles push the cost of petroleum solvent distillation much higher: the low value of recovered solvent[5] relative to halogenated solvents and the flammability of petroleum solvents, which requires many equipment safety features.

Stills can reduce the solvent volume content from the 70 to 90 percent found in vapor degreasing waste to 20 percent. Some disposed petroleum solvents can be reused in oil furnaces as fuel; simple filtration will prepare the solvents for burning. Disposed solvents containing lubricants with chlorine or sulfur additives are not useful in oil furnaces because of air pollutants in the additives.

Companies that decide not to burn fuel or buy stills can contract with reclaimers that perform distillation and return the solvent. The cost is approximately half the market value.

Another disposal option is to sell the solvent to a reclaimer, who usually offers low prices for disposal. In this case, the reclaimed solvent is not sold back to the company.

COMBINATIONS OF PROCESS CHANGES

Combining some of the process changes described above, increased freeboard, refrigerated chillers, and distillation equipment, can increase their effectiveness in emission control. Results of these combinations are shown in Table 1.

It should be noted that distillation equipment is compatible with all the process changes listed in this chapter. When process changes are made, there will be the same or slightly greater amounts of contaminated solvents to dispose of; the greater amounts, where they occur, will result from the loss of stabilizers. When emission losses occur normally, the makeup solvent contains fresh stabilizers. When emission losses are curtailed, less makeup is required, and the stabilizers are consumed more rapidly. This requires either more frequent disposal or the addition of stabilizing solvents.

The combined effectiveness of covers and increased freeboard is estimated at 5–15 percent greater than the effectiveness of covers alone. The reason this figure is less than the sum of their individual effects is that freeboard and covers overlap in preventing solvent emission from drafts. The combined effectiveness of chillers and covers is 16–43 percent greater than the effectiveness of the chiller alone, the higher percentage being for the more volatile methylene chloride. The reason chiller and cover effects are not completely cumulative is that they share the effect of preventing convection idling losses; however, their dual effect is increased because chillers do not prevent sump shutdown evaporation losses.

There are no test data available on emission reduction with combinations of increased freeboard and chillers.

Table 1

Comparison of Process Changes for Reducing Hydrocarbon Emissions

Emission Reduction Technique	Solvent[a] Reduction Effectiveness	Profitability	Effectiveness When Combined With Other Process Changes
Covers	24-50% 5%	Generally profitable	With Freeboard: 5-15% greater than cover With Chillers: 16-43% greater than chillers With Distillation: Additive
Increased Freeboard	27-55% 30%	Generally profitable with the exception of methylene chloride and trichlorotrifluoroethane where freeboards are already increased	With Covers: 5-15% greater than cover With Chillers: No data With Distillation: Additive
Refrigerated Chillers	16-60%[b] 40% 35-77% 57%	Generally profitable with the exception of small tank only one-shift operation	With Covers: 16-43% greater than chiller[c] With Freeboard: No data With Distillation: Additive
Distillation	80% of disposed solvent	Profitable above 350 gallons per year of halogenated solvent	Can be combined with all other process changes. Combined effectiveness is additive.

(a) upper sets of numbers is range, lower set is expected efficiency
(b) two sets of test results
(c) 16% for 1,1,1-trichloroethane and 43% for methylene chloride

CHAPTER V

TECHNIQUES FOR TREATING SOLVENT CLEANING EMISSIONS

Current techniques for treating solvent emissions, used in conjunction with process changes that reduce them (Chapter IV), can bring solvent metal operations into line with air pollution standards.

Certain features of solvent emissions discussed below are relevant to treatment techniques.

CHARACTERISTICS OF SOLVENT EMISSIONS

The characteristics of solvent cleaning emissions that most affect pollution control treatment are:

- Percent of ventilation airflow that can be captured;
- Solvent emission concentration in the airflow;
- Rate of airflow;
- Temperature of airflow;
- Number of compounds present in the emissions; and
- Range of variation in the above characteristics.

The effectiveness of any treatment device in reducing solvent consumption depends on the percentage of escaping emissions that can be entrapped and channeled into the device. For instance, considerable amounts of emissions come from drag-out; most of these evaporate beyond the capture point of the ventilation system.

It is estimated that from 25 to 55 percent of all solvent emissions cannot be captured for treatment. For example, carbon adsorption systems, to be described later, reduce solvent consumption by an average of 40 percent; the highest tested achieved a 65-percent reduction. Yet carbon adsorbers are 90-95 percent effective in controlling solvent emissions drawn into them. A 90-percent effective, properly designed carbon adsorber that reduces solvent consumption for a total cleaning system by only 40 percent is receiving less than half the solvent cleaner emissions. Where the solvent consumption reduction reaches 65 percent, the carbon adsorber is receiving no more than three-quarters of the emissions.

Solvent concentrations in the airflow from solvent cleaners will vary considerably due to intermittent workloads. For example, open top tank degreasers may operate only 25 percent of a shift, during which time the exhaust fan is always on. The expected concentration variation is from 50 ppm to 1000 ppm, with the average between 100-500 ppm.

Air flow rates range from 50 to 125 cfm/ft^2 of opening area.

Temperatures of solvent degreasing emissions range from room temperature to 125°F.

Where single-solvent cleaners are used, the compound present in the airflow will be the same as the solvent. With petroleum solvents and other solvent blends, the differences in hydrocarbon compounds will affect the efficiency of some treatment devices, notably carbon adsorption.

TECHNIQUES FOR CONTROLLING SOLVENT EMISSIONS

The choice of techniques to control solvent cleaning emissions is relatively limited, and includes condensation, absorption, incineration, and carbon adsorption.

CONDENSATION

Where low efficiency is acceptable, condensation of vapors is possible. The entire airflow must be chilled to a point where the partial pressure of the solvent at that temperature will result in a vapor concentration that is substantially less than the vapor concentration in the air stream. An amount of solvent equivalent to the difference in vapor concentrations can then condense on a cold surface. In actuality, something less than the theoretical amount will be removed because of equilibrium rate factors, the heat evolved, and droplet losses. Where airflow rates are low, vapor concentrations high, and the solvent expensive, condensation may be economical. In solvent cleaning, however, flows are normally too high and vapor concentrations too low for economical chilling operations.

ABSORPTION

Absorption is a common industrial technique for separating vapors from a carrier gas stream. For it to be effective, a scrubbing liquid (absorbent) must be available in which the solvent is either soluble or will react to form a less volatile compound. The absorbent in itself must not release undesirable vapors under operating conditions, and the solvent must be separable from the absorbent unless the mixture can be economically and safely wasted. For the halogenated hydrocarbons typically used in solvent cleaning, there are no known absorbent materials that meet the above criteria. Attempts have been made to use mineral oil to collect trichloroethylene vapors, but emissions from the mineral oil itself have been excessive.

INCINERATION

Heating the air stream to temperatures of 1200°F - 1500°F will destroy solvent vapors. Carbon and hydrogen will be converted to CO_2 and water. However, the halogens will burn to compounds such as phosgene, hydrochloric acid, and hydrofluoric acid, and unless these are removed in a second-stage collector, they may become a more serious source of air pollution than the original solvent vapors. Additional disadvantages of incineration are the loss of recovered-solvent benefits and the high fuel requirement for burning air streams with low concentrations of combustible vapors. Incineration, therefore, is generally too expensive for the low solvent concentrations from degreasers and even more so for secondary control of incinerator halogen emissions. It is not often a serious contender for degreaser emission control.

CARBON ADSORPTION

Adsorption, almost universally using activated carbon beds, is the most effective control system for halogenated and petroleum solvent cleaning emissions. Because of its importance, we will discuss it here in detail.

The carbon adsorption technique uses regenerative activated carbon to remove gaseous molecules from an air stream in three distinct phases: adsorption, desorption, and disposal or recovery of the adsorbed material. (Note that the term adsorption can refer to the entire process or the first phase.) "Regenerative" means that the carbon can be used repeatedly after the captured gases are removed. "Activated" refers to the treatment that gives the carbon its adsorptive properties: the carbon is heated in the absence of oxygen, removing tars present in the pores, and subjected to high-pressure steam to create a network of micro-capillaries that will collect organic molecules.

The principle of carbon adsorption is based on the attraction between gaseous molecules and the molecules forming a solid surface. The attractive or capturing force, known as van der Waals force, occurs at the point where the gas and the solid meet. It takes place when a fluctuating dipole moment in a non-polar molecule induces the same in another non-polar molecule, whereupon they interact. The force holds the molecule to the solid surface. As more gaseous molecules come in contact with the surface, a monomolecular and then a multimolecular layer builds up. The molecules can then be removed by the application of heat.

The term "force" is used to differentiate a physical attraction from a chemical reaction, which can also occur at the interface of a solid and a gas. When a chemical reaction occurs, the process is called chemisorption and can be detected by a chemical change in the gaseous molecule. In other words, if the gaseous molecule is removed from the solid surface by attraction and its identity has been retained, then the van der Waals force prevailed. A chemical change in the removed molecule indicates chemisorption, which usually requires more energy for separation.

Among the best adsorbers are activated carbon and silica gel, the former being used much more extensively, since silica gel prefers to adsorb water (polar) over

organics (non-polar). The unique characteristics of both these solids is the large number of micro-capillaries that provide large surface collection areas. The range of solid particles used in adsorption is from .5 inches down to 200 microns.[8]

Carbon particles are carefully selected to yield a porous but strong granule. Once activated, the carbon is packed loosely as granules or glued together into chambers called beds. Surface areas of activated carbon are typically 1100 m^2/gram expressed in weight or 2 x $10^8 ft^2/ft^3$[2] expressed as a volume ratio.

The absolute retention capacity of a given adsorbent for a particular solvent will depend on the solvent, the material from which the carbon is made, the manufacturing process, and the conditions of use. For activated carbon, manufacturers specify maximum capacities based on specified solvents and test conditions. Published values for useful carbons range from about 0.4 (40%) to approximately 1.0 (100%) grams of solvent adsorbed per gram of carbon.

Because it is impractical to remove all the captured solvent before the solvent bed is put back on stream after regeneration, the actual working capacity of the bed after use is considerably lower than the maximum stated capacity. Table 2 shows typical working bed adsorption capacity for some common solvents:

Table 2

Working Bed Capacities[(a)]9

Solvent	% of Carbon Bed Weight[(b)]
Acetone	8
Heptane	6
Isopropyl Alcohol	8
Methylene Chloride	10
Perchloroethylene	20
Stoddard Solvent	2-7
1,1,1-Trichloroethane	12
Trichloroethylene	15
Trichlorotrifluoroethane	8
VM&P Naphtha	7

(a) Assuming steam desorption at 5-10 psig
(b) Excluding weight of adsorbed solvent

A discussion of some more specific aspects of carbon adsorption (listed below) will give readers the practical information they need.

- Airflow conditioning for carbon adsorption
- The adsorption phase
- The desorption phases and disposal/recovery
- Adsorption effectiveness
- Adsorption equipment
- Adsorption costs

Airflow Conditioning for Carbon Adsorption

Extraneous materials such as dust, tars, and mineral oil will clog the capillary pores of carbon beds and reduce adsorption capacity. Other materials, particularly certain metallic compounds, can cause undesirable chemical reactions in the bed. Excessive moisture, if condensation occurs, can physically block the carbon pores. When these substances are present in harmful amounts, precleaning or conditioning of the gas stream may be necessary.

Filters are commonly used with carbon adsorbers to eliminate dust or paint spray contaminants. Moisture is not an insurmountable problem because activated carbon adsorbs organic matter in preference to water. However, although activated carbon is less sensitive than silica gel to high gas-moisture content, its adsorption capacity may be lower with a dry gas stream. For excessively humid air, the temperature of the stream can be increased to lower the relative humidity, a demister can be used, or the moisture can be condensed by cooling.

The Adsorption Phase

Certain variable factors affect the efficiency of carbon adsorption. Several of the more important ones are gas velocity and direction, preferential adsorption, and temperature.

Gas Velocity and Direction

In most adsorption units, the gas enters the activated carbon bed from top to bottom (Figure 8). Downflow allows the use of higher gas velocities; in upflow, the velocity must be limited to a value that will not lift the carbon, because this would result in reentrainment of the adsorbent.[6] Some units, however, have been deliberately constructed as fluidized bed systems, with upflow velocities sufficient to suspend but not remove the carbon from the bed. This prevents the clogging of the bed by contaminants or the breakdown of granules to small sizes during regeneration. However, the accelerated carbon attrition caused by the impact between granules results in high carbon-replacement costs.

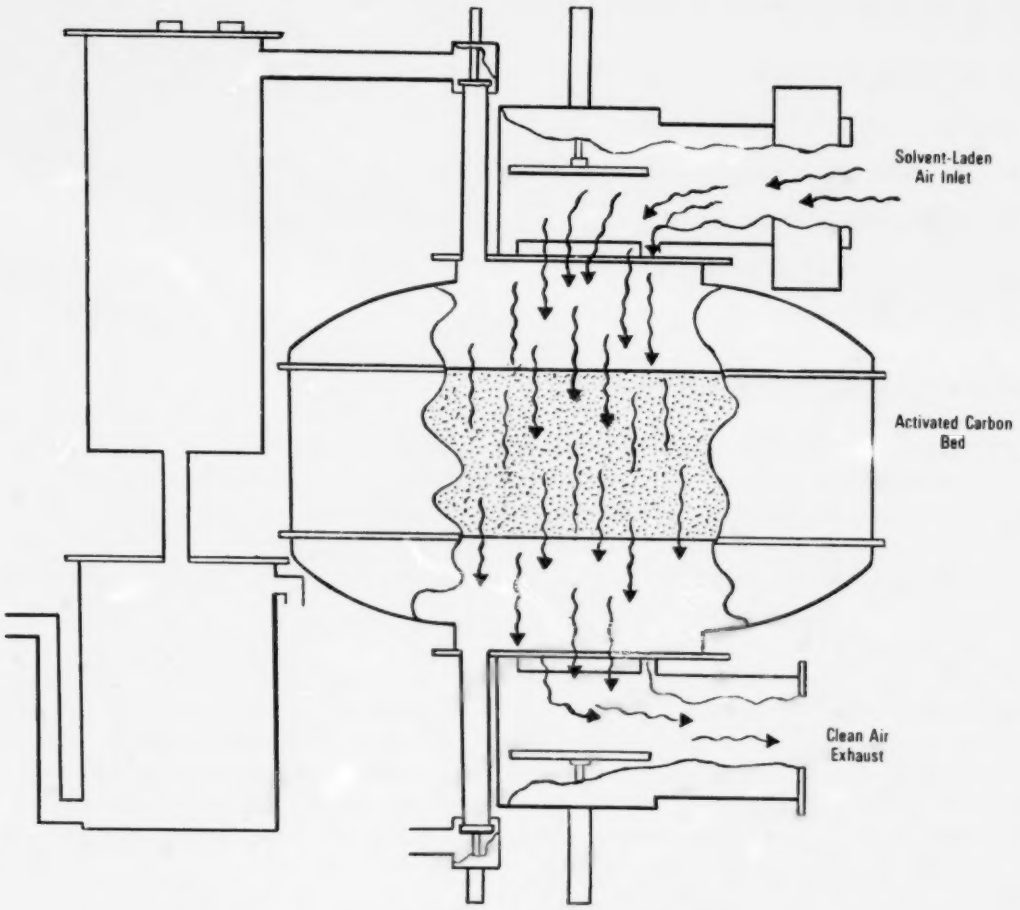


Figure 8. Adsorption Cycle

Downward velocities through the bed are limited by the crushing effects of the gas on the activated carbon and the length of the Mass Transfer Zone (MTZ). The crushing velocity limit for each type or size of activated carbon is specified by the manufacturers.

The MTZ is the zone of partial saturation between the fully saturated zone adjacent to the entrance to the bed and the nonsaturated zone at the exit of the bed. For best operation, it is important to have a short mass transfer zone in the adsorber (usually about 2"). Initially, collection occurs at the upstream face and the MTZ moves toward the outlet side. The operator usually stops the adsorption in a bed when the MTZ reaches the outlet of the bed (commonly when there is one percent of inlet concentration). The capacity of the bed is therefore greater with a short MTZ. Because the MTZ of a bed lengthens with increased velocity, it is desirable to keep low velocities.

Preferential Adsorption

When the properly conditioned, hydrocarbon-laden gases enter the carbon bed in a downward direction at the preferred velocity, adsorption occurs between the hydrocarbon molecules and the activated carbon. However, activated carbon will adsorb organic molecules in a preferential manner. Non-polar organic molecules are preferentially adsorbed by activated carbon over polar organic molecules. Although both molecules will be adsorbed by the activated carbon (which is non-polar), a non-polar molecule can replace a polar molecule. Therefore, if both types of molecules are present in the inflow, it is likely that the emissions will consist of polar molecules at breakthrough.

Higher boiling point (or molecular weight) molecules are also preferentially adsorbed over lower boiling point molecules, meaning that the more volatile, low boiling point hydrocarbon molecules will be present at breakthrough; if the adsorption capacity along their path is saturated and there are no lower weight molecules to replace, they will exit the bed. Moisture is also adsorbed by activated carbon, but most of it is preferentially replaced by organic molecules. Exceptions occur in which moisture condenses and physically clogs the capillaries.

Temperature

Adsorption, an exothermic process, releases heat to the activated carbon bed. For typical degreasing concentrations, the temperature of the bed may increase by only 10°F - 20°F. This temperature increase will slightly reduce the adsorption capacity of the bed, but does not disrupt the collection process. With high concentration vapor streams, some form of cooling will be required. This may involve cooling the entire air stream before it reaches the bed or embedding cooling coils in the charcoal. The latter approach is more common, but complicates carbon replacement.

Selection of an Adsorbent

In addition to temperature and gas velocity, discussed above, there are a number of other controllable factors that influence the adsorption process. These factors enable activated carbon to be tailored to adsorb many different chemical compounds at different efficiencies. Adsorption-equipment manufacturers work closely with activated-carbon suppliers, who have considerable information on the effects of these design variables. Manufacturers of adsorbers can provide quotations based on information given them about cfm, temperatures, solvents to be adsorbed, operating hours, and concentrations.

Important features in the design of an adsorbent are:

- Carbon Surface Area. As noted, adsorbent capacity is directly proportional to the carbon surface area. The maximum surface area for a given carbon bed is a function of the starting material, the production method, and the efficiency of activation. Production techniques are generally considered proprietary by the manufacturer.

- Pore Size. For a given use, this may also be a significant factor. At low solvent concentrations, the smallest pore size through which the adsorbate can enter is the most efficient, while at higher concentrations larger pores are more efficient. This principle is illustrated in Figure 9. At very high pressures, capillary condensation takes place within the pore, and total micropore volume determines effectiveness rather than pore size.
- Physical Toughness. Resistance to crushing and attrition is also important in an adsorbent. This property is most dependent on the starting material, but can be significantly influenced by the production method. Coatings and form of the carbon (glued slab vs. granules) also influence strength.

There are a number of other variables—some of them plant operating factors—that should be considered in selecting or designing an adsorbent for a specific use, including:

- Adsorbent particle sizes;
- Adsorbent bed depth;
- Adsorbate concentration;
- Pressure effects;
- Bed geometry;
- Decomposition or polymerization of the adsorbate; and
- Intermittent operations.

For a definitive discussion of these factors, the reader can consult any of the specialty texts on adsorption. However, the principal points are summarized below.

Adsorbent Particle Size

"The dimension and shape of the carbon particle size affects both the pressure drop through the adsorbent bed and the diffusion rate into the particles. The pressure drop is lowest when the adsorbent particles are spherical and uniform in size."[7] Pressure drop is directly proportional to velocity and inversely proportional to particle size. Adsorbent beds consisting of smaller particles require greater pressure drops but have better collection efficiency. Small particle beds are characterized by a sharper and smaller MTZ.

Adsorbent Bed Depth

The first consideration in bed size is that the depth of the bed should be greater than the length of the MTZ, otherwise breakthrough will occur too quickly after initial adsorption. An adsorbent bed should be sized to the maximum depth allowed by pressure drop considerations. Bed depths of 1 1/2 - 3 feet are common.

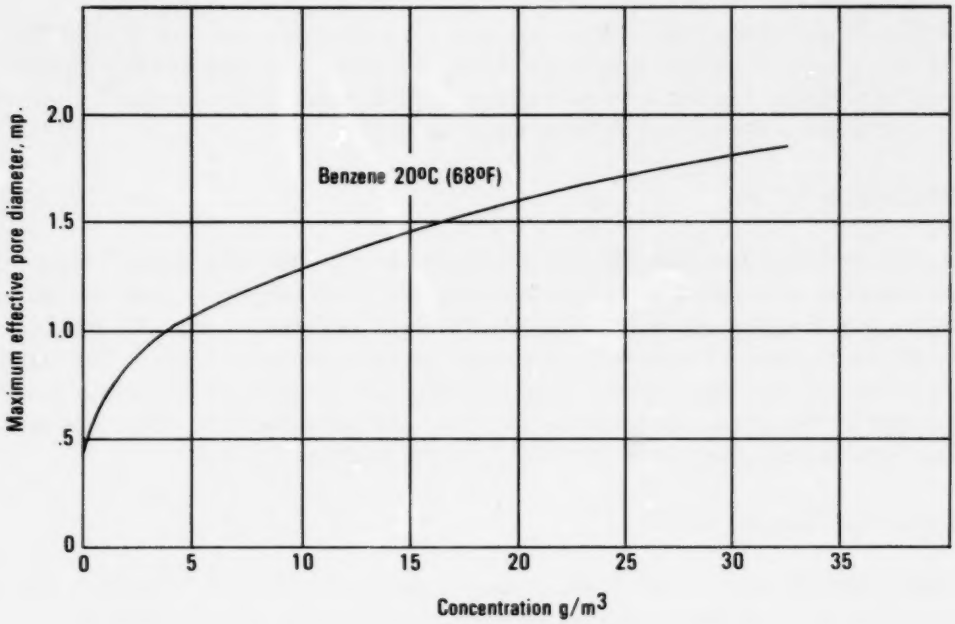


Figure 9. Sizes of Carbon Pores Effective in Adsorption

Adsorbate Concentration

The solvent retention capacity of carbon is directly proportional to the concentration of the solvent. Thus, everything else being equal, a deeper bed will be required to collect a low concentration of contaminant than to collect the same contaminant at higher concentrations.

Pressure Effects

The saturation adsorption capacity of a bed increases in proportion to increasing pressure within the bed. Where a long bed is used, the pressure drop across the bed will cause a significant difference in adsorption capacity between the upstream and downstream face.

Adsorbent Bed Geometry

Bed volume is the key design factor in adsorption removal efficiency. For a given volume, the depth and diameter must be balanced to achieve acceptable face velocities (which affect pressure drop, crushing, and the length of the MTZ) and a reasonable depth (which retards the tendency to short circuit and affects the average saturation concentration obtainable). Reducing the bed volume theoretically reduces only the cycle time, but in practice it also tends to reduce the efficiency of collection.

Decomposition and Polymerization of the Adsorbate

Organic molecules may decompose or polymerize because of temperatures of the gas stream, stripping temperature, or the presence of catalysts. Decomposition or

polymerization of molecules can change the overall adsorption rate and reduce the capacity of the system. Severe polymerization may require either periodic high-temperature reactivation of the bed or frequent replacement of the carbon. However, this is not a problem with typical solvent cleaning vapors.

Intermittent Operations

Short, intermittent operation cycles generally do not affect the overall capacity of the adsorption system if the bed depth equals several MTZ lengths. Long periods of intermittent operation, particularly in small systems, will lower capacity because of the longer MTZs produced by solvent migration during inactive periods. The continued circulation of the carrier gas without contaminants also causes the adsorbate to diffuse through the bed by desorption into the carrier gas and readsorption. Thus, when no contaminant is being emitted, it is preferable to shut off the blower.

The Desorption and Recovery Phases

Once an activated carbon bed is saturated, it can either be discarded or regenerated by removing the hydrocarbons (desorption) and then returning the bed to service. These choices are determined more by economics than by the nature of the hydrocarbons. In most solvent degreasers using activated carbon, it is cheaper to regenerate the beds.

Regeneration requires heat for raising the partial pressure of the solvents and causing them to revolatilize. The larger the percentage of captured solvent that can be removed from the bed, the greater its capacity for further service. (The solvent not removed is called the heel.) Although higher temperatures and longer application of heat increase solvent removal, there is an economic limit.

Desorbing (stripping) and recovering or disposing the captured hydrocarbons from the bed may involve a number of factors:

- Steam
- Hot air
- Hot inert gas
- Settling
- Distillation
- Incineration
- Readsorption
- Condensation.

The commonest form of desorption uses a counter-current flow of low temperature steam (5 - 10 psig) through the bed after the bed has been closed off to pollutant flow (Figure 10). The incoming steam condenses and heats the bed and then acts as a flush

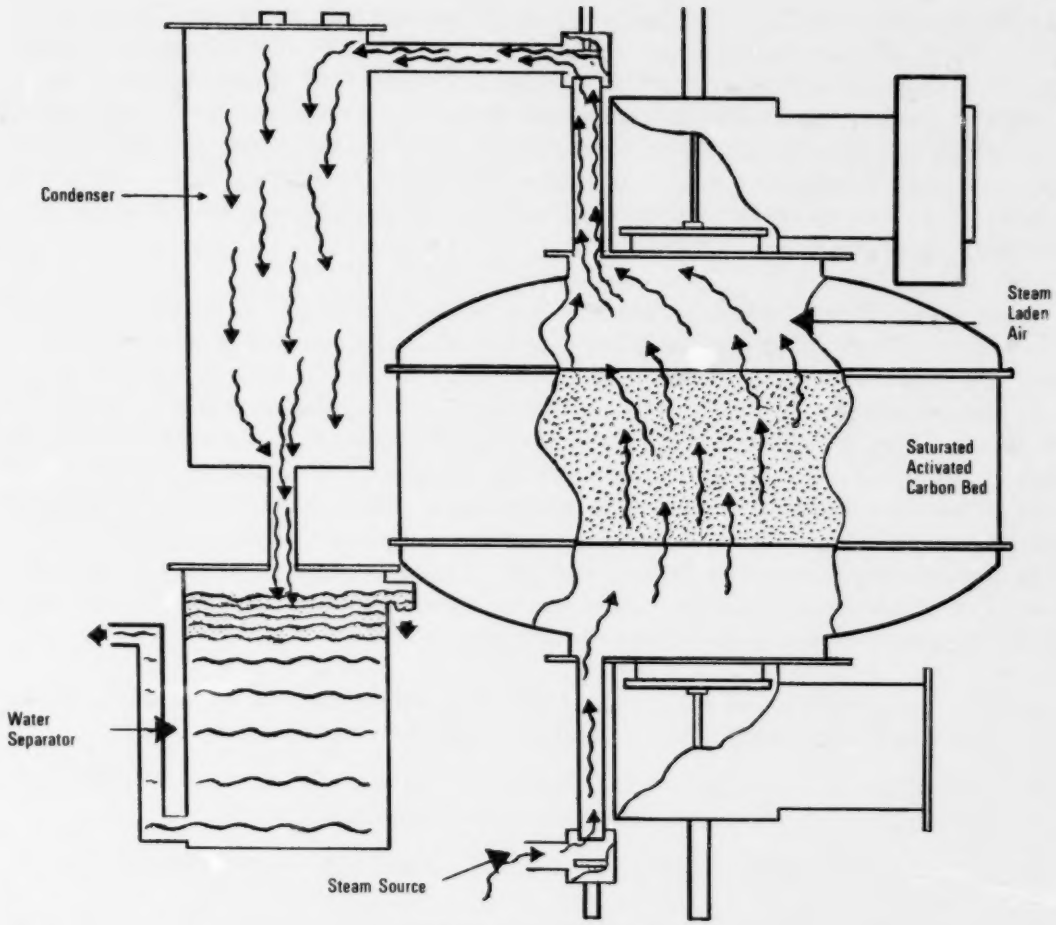


Figure 10. Desorption Cycle

gas to strip solvent from the bed. The steam and solvent can be routed to a water-cooled condenser for liquification. If the steam-to-solvent ratio does not greatly exceed a minimum of 3 - 5 pounds of steam per pound of solvent, simple decantation is sufficient to separate immiscible solvents from the water. However, distillation may be required for mixtures with larger water-to-solvent ratios or miscible solvents.

The stripped carbon bed is then cooled, usually by dry air, and returned to use. If temperature increases during adsorption are a problem, enough water can be left in the bed to lower them. The moisture remaining will not affect adsorption, since the moisture is preferentially replaced by organic molecules.

The cost of steam for desorption is an important factor in the total cost of an adsorption system, making accurate assessment of steam requirements an essential part of the design process. As noted earlier, the working adsorption capacity of a carbon bed is the difference between the theoretical adsorption capacity and the saturation concentration of solvent remaining after desorption. For a given solvent and carbon, the saturation value is a function of the solvent concentration in the carrier gas and

the operating temperature. At a working bed temperature in the normal range of 105°F - 120°F, the saturation capacity decreases rapidly with decreasing concentration in the air. Desorption is also more difficult at low solvent-to-carbon ratios. Thus, the working capacity of the bed decreases and the steam requirements for regeneration increase with lower incoming vapor concentrations. For inlet vapor concentrations above 1000 ppm, from 3 to 5 pounds of steam will be required per pound of solvent recovered. This will increase to about 30 pounds of steam per pound of solvent at an inlet vapor concentration of 10 ppm.[7]

When steam desorption requirements rise to the level of 5 - 10 pounds of steam per pound of solvent removed, the solvent in the mixture produced by condensation is dilute. Decantation for separation is difficult, and for slightly soluble solvents sewer losses may be excessive. Under these conditions, hot-gas desorption may be more economical. Air, flow gas, or an inert gas may be as effective as steam, pound-for-pound, in stripping solvent vapors from carbon, although the initial heating of the bed is slower because there is no condensation heat gain. This may be offset by using a regeneration gas temperature of 300°F or higher, if decomposition, polymerization, or fire does not constitute a problem. Hot gas is considerably cheaper than steam, but the cost of secondary recovery is generally higher except in large steam-to-solvent ratios. Recovery of the solvent from the hot gas may be accomplished by:

- Passing the gas through a small carbon bed, which may be conventionally regenerated with steam on a low pounds-steam to pounds-solvent basis;
- Cooling the gas stream to cause partial condensation of solvent and passing the remainder of the contaminated gas to the on-line adsorber; or
- For petroleum hydrocarbons, burning the solvents in a fume incinerator.

Steam desorption of petroleum-solvent blends with boiling points above 300°F is difficult. Sometimes superheated steam (343°C) is required, with a significant cost increase over low temperature steam.

Steam desorption creates small amounts of organic water pollution.

ADSORPTION EFFECTIVENESS

Recent tests for carbon adsorption based on five adsorbers show overall solvent usage reductions of 20 - 65 percent. Carbon adsorption systems with average inlet concentrations of 500 ppm can achieve 95-percent control, or an average outlet concentration of 25 ppm. The carbon bed itself is more than 90-percent effective in removing pollutants from gas streams that enter it; however, the drag-out source of emissions prevents many vapors from reaching the bed. Thus, minimizing drag-out emissions and capturing most of the vapors is critical to the overall effectiveness of carbon adsorption systems.

The lower efficiencies reported were, in part, attributable to intermittent production rates. During slack intervals, the low inlet concentrations and moving air cause

hydrocarbons to migrate deeper into the bed and cause more rapid breakthroughs. Another cause of low efficiencies was high fan speeds, leading to excessive emissions from drafts and rapid breakthrough.

The five adsorbers tested all used steam stripping. The tests showed that recovered solvents often require restabilization by additions of stabilizing solutions. The acetone and alcohol cosolvents used with trichlorotrifluoroethane are lost during bed-regeneration by steam because these stabilizers react with the water.

Although petroleum solvent blends were not a part of these tests, recovered amounts would be of different composition than the original blend in the degreaser. Therefore, it may not be possible to put recovered petroleum solvent blends directly back into the cold cleaning degreaser.

The use of carbon adsorbers with automatic covers is somewhat self-defeating, because when the cover is closed the previously captured solvent will migrate in the bed with additional air movement. Controls can be designed to shut off the adsorbing fan when the cover is closed.

The construction materials for the adsorption bed housing should be mild steel with a phenolic resin coating where steam regeneration is used, because high temperatures and the affinity of carbon for water can cause formation of hydrochloric acid from disassociation of the chlorinated solvents. In other operations, materials with less corrosion resistance can be used where there is low moisture content. The carbon adsorbers are commonly connected by ductwork to the lip exhaust system. It is important for plants to control fan speeds to minimize ventilation rates. This is true for either a package-unit fan or a plant exhaust fan.

ADSORPTION EQUIPMENT

For batch or noncontinuous degreasing operations with low emission concentrations, a single adsorbing bed can be used for the entire system. The bed is sized to operate during a degreasing cycle, or perhaps a single shift. On completion of the cycle, there must be sufficient downtime to allow regeneration of the bed before further degreasing.

Beyond a certain bed size or cycle time, economics dictates multiple beds to provide continuous operation. Most small degreasing operations use two beds; larger operations may have three. One bed can be collecting while a second bed is regenerating and the third bed is drying. The first bed can collect to saturation, and the clean effluent gas can be passed through the drying bed for quicker drying. When the first bed is saturated, the dried bed is ready for collecting. The first bed is then regenerated and the bed that was regenerating enters the drying phase. In this way, the cycle goes on.

Often beds are not connected in series, and the effluent gas from the adsorbing bed goes to the atmosphere. When the bed reaches breakpoint or the allowable emission rate, the adsorption process is switched by dampers to a second bed. This arrangement is more common and is standard design practice for package adsorption units up to 10,000 cfm capacity. The manufacturer runs tests to determine the typical amount

of time for the bed to reach breakpoint. A safety time factor is applied and bed switching occurs at preset time intervals. Timers are used rather than monitoring devices, because reliability of the latter is questionable over long periods.

Carbon adsorption systems require considerable maintenance to keep them functioning properly. Special attention should be given to:

- Reliable valve and damper functioning;
- Changes in carbon bed switching time as a function of changing production rates; and
- System leaks.

ADSORPTION COSTS

This section will give the results of cost analyses performed for existing adsorption systems and will present a form that plant personnel can use to estimate their own adsorption costs.

As noted in Chapter IV, the use of covers and increased freeboard will generally return a profit, as will the use of refrigerated chillers. The overall profitability of carbon adsorption systems is dependent upon the emission concentration and the market value of the recovered solvent. Cost calculations for trichloroethylene show that carbon adsorbers can be operated on a profitable basis when bed inlet emission concentrations are above 200 ppm. However, there are no data on the distribution of emission concentrations from various sources. Therefore, general statements—such as those made for certain process changes—cannot be made about the use of carbon adsorption systems by the industry.

Because of the complexities of calculating the costs of carbon adsorption systems, a form has been developed to help plant personnel estimate the capital and operating costs.

The following example illustrates the use of the form. A blank cost calculation form is included as Appendix A to allow plant personnel to estimate their adsorption costs.

General Design Data

Gas Flow, Q = 3000 scfm

Solvent: Trichloroethylene

Solvent Concentration, S = 500 ppm

Solvent Molecular Weight, MW = 135.5

Solvent Value, V = $2.15/gallon

Operating Hours, H = 2080 per year

Adsorber Type: 2 tank, automatic

Adsorber Unit Price, U = $4.67/scfm

(a) Package Adsorber

The adsorber equipment cost is found by multiplying the adsorber unit price (U) and the gas flow (Q). The installed cost of the adsorber would be the sum of the equipment and installation costs. It is convenient to use a factor called the installation cost factor (ICF) to obtain installed cost, C^1:

$$C^1 = \text{equipment cost} \times ICF$$

The value of the ICF will vary with the complexity of the job, space available, and modifications needed to the process before the adsorber can be added. Here a value of 2.0, a value typical of many installations, is chosen for the installation cost factor.

To determine a year's amortization, this cost is multiplied by a factor called the capital recovery factor (CRF). The value of the CRF depends on the interest rate and the useful life of the equipment, and is arrived at by the following formula:

$$CRF = \frac{i(1+i)^{n^1}}{(1+i)^{n^1} - 1}$$

where: i = interest rate, expressed as a fraction

n^1 = useful life of the adsorber in years

In this example, it is assumed that the interest rate is 10% ($i = 0.1$) and the useful life (n^1) is 15 years. The capital recovery factor is:

$$CRF = 0.1315$$

The annual package adsorber capital cost is given by the formula:

$$U \frac{\$}{scfm} \times Q \text{ scfm} \times ICF \times CRF$$

(b) Space

This cost is the yearly value of the space taken by the adsorber installation, and is given by

$$A \frac{\text{sq. ft.}}{\text{scfm}} \times Q \text{ scfm} \times C^A \frac{\$}{\text{sq. ft.}} \times \text{CRF}$$

where A = unit area occupied by the adsorber

C^A = cost per sq. ft. of space

The value for A is typically 0.045 sq. ft./scfm. C^A is assumed here to be \$40/sq. ft. The CRF for the space cost is found by assuming a 25-year useful building life (n^2) and 10% interest rate ($i = 0.1$).

$$\text{CRF} = 0.1102$$

(c) Steam

This cost is determined by multiplying the cost of steam (C^S, \$/lb steam) and the lbs. of steam needed (P^S) and is given by the formula:

$$P^S = (78 + 0.04\ S^{1.085}) \times 10^3 \times Q \times H$$

The cost of steam C^S is assumed here to be \$1.50 per 1000 lbs., or \$0.0015/lb. steam.

(d) Water

This cost represents the cost of water (C^W, \$/lb. water) times the amount of water needed to condense the steam (P^W, lbs.). It is assumed here that the cost of water is 15 cents per 1000 gallons, or

$$C^W = \frac{\$0.15}{1000 \text{ gallons}} \times \frac{1}{8.37} \frac{\text{gallon}}{\text{lbs.}} = 1.8 \times 10^{-5} \text{ \$/lb. water}$$

A typical value for the amount of cooling water needed is 30 lbs. water per lb. of steam, and will be assumed here. Thus

$$P^W = 30 \times P^S \text{ lbs.}$$

The value of P^S is determined from the formula given in (c) above.

(e) Electricity

The cost of electricity is found by multiplying the cost per kwh (C^K, \$/kwh) and the kwh consumed by the fan. The kwh consumed by the fan is given by:

$$F \frac{kw}{scfm} \times Q \text{ scfm} \times H \text{ hrs}$$

where: F = fan power per scfm, and is typically 0.003 $\frac{kw}{scfm}$

The cost per kwh is assumed here to be 4 cents per kwh, or

$$C^K = \$0.04/kwh$$

(f) Carbon Replacement

This cost is the price of carbon (C^C, \$/lb) times the amount of carbon replaced per year (P^C, lbs). Carbon replacement needs depend on such factors as fouling and loss due to abrasion. It is assumed here that 300 lbs. of carbon will have to be replaced every 5 years per 1000 scfm of adsorber capacity. Thus:

$$P^C = \frac{300 \text{ lbs.}}{1000 \text{ scfm}} \times Q \text{ scfm} \times \frac{1}{5}$$

$$= \frac{300}{1000} \times 5000 \times \frac{1}{5}$$

$$= 180 \text{ lbs. annually}$$

The price of carbon, C^C, is assumed to be \$1.00/lb.

(g) Operation

For manual systems, this cost is found by multiplying hourly labor cost (C^L, \$/hr.) and the number of labor hours needed annually for steam regeneration (H^L).

The hours needed for regeneration will depend on the solvent concentration: the higher the concentration, the less time needed to regenerate. H^L is given by the following empirical formula:

$$H^L = \frac{S^{0.7}}{125} \times H \text{ (for manual systems)}$$

For automated systems, this cost is also calculated by multiplying hourly labor cost, C^L, and the labor hours needed, H^L.

However, in this case the labor hours are calculated by assuming that 15 minutes of labor is needed per 8-hour shift. Thus:

$$H^L = 15 \text{ minutes} \times \frac{1 \text{ hour}}{60 \text{ minutes}} \times \frac{1}{8} \times H$$

$$= 0.03125 \times H \text{ (for automated systems)}$$

The labor cost, C^L, is assumed here to be \$10/hr.

(h) Maintenance, Insurance and Taxes

These costs can be conveniently expressed as percentages of installed cost, C^I. Typical values are:

$$\text{maintenance} = 5\% \text{ of } C^I$$
$$\text{insurance} = 1\% \text{ of } C^I$$
$$\text{taxes} = 1\% \text{ of } C^I$$

Installed cost is given, as in (a), by:

$$C^I = \text{Equipment Cost} \times \text{ICF}$$
$$= U \times Q \times \text{ICF}$$

(i) Solvent Credit

Solvent credit is value of solvent (V, \$/gal.) times solvent recovered (R, gallons). 90% recovery is assumed here:

$$R = 0.9 \times \text{solvent recoverable}$$

$$= 0.9 \times 1.67 \times 10^{-7} \times S \times MW \times Q \times H \times \frac{1}{D} \text{ gallons}$$

$$= 1.5 \times 10^{-7} \times S \times MW \times Q \times H \times \frac{1}{D}$$

where D is the solvent density in lbs/gallon.

The following pages show how costs were calculated for the data used in the above example, using the cost calculation form in Appendix A.

EXAMPLE CALCULATION – ADSORPTION COSTS

General Design Data

Solvent: Trichloroethylene
Solvent Concentration, S = 500 ppm
Solvent Molecular Weight, MW = 135.5
Solvent Value, V = $2.15 per gallon
Gas Flow, Q = 3000 scfm
Operating Hours, H = 2080 per year
Adsorber Type: 2-tank, automatic
Adsorber Unit Price, U = $4.67 /scfm

Annualized Capital Costs:

a) Package Adsorber

- additional data

  installation cost factor, ICF = 2.0
  useful life of adsorber, n^1 = 15 years
  interest rate, i = 10 per cent = 0.1 (expressed as a fraction)

- capital recovery factor, CRF

$$CRF = \frac{i(1+i)^{n^1}}{(1+i)^{n^1} - 1} = \frac{0.1(1+0.1)^{15}}{(1+0.1)^{15} - 1} = 0.1315$$

- annualized package adsorber cost

  $= U \frac{\$}{scfm} \times Q \text{ scfm} \times ICF \times CRF$

  $= 4.67 \times 3000 \times 2.0 \times 0.1315$

  $= \$3684.63$

b) Space

- additional data

  unit area occupied by adsorber, A = 0.045 sq.ft./scfm
  cost per square foot of space, C^A = $40 /sq.ft.
  useful building life, n^2 = 25 years

- capital recovery factor, CRF

$$CRF = \frac{i(1+i)^{n^2}}{(1+i)^{n^2} - 1} = \frac{0.1\ (1+0.1)^{25}}{(1+0.1^{25})-1} = 0.1102$$

- annualized space cost

$= A \ \frac{\text{sq. ft.}}{\text{scfm}} \times Q \text{ scfm} \times C^A \ \frac{\$}{\text{sq.ft.}} \times CRF$

$= 0.045 \times 3000 \times 40 \times 0.1102$

$= \$\ 595.08$

Operating Costs

c) Steam

- additional data

cost of steam, $C^S = \$\ 0.0015$/lb. steam

- lbs. of steam needed, P^S

$= (78 + 0.04\ S^{1.085})\ 10^{-3} \times Q \times H$

$= (78 + 0104 \times (500)^{1.085}) \times 10^{-3} \times 3000 \times 2080$

$= (78 + 33.92) \times 10^{-3} \times 3000 \times 2080$

$= 698,374$ lbs.

- annual steam cost

$= C^S \times P^S$

$= 0.0015 \times 698374$

$= \$\ 1047.56$

d) Water

- additional data

  cost of water, C^W = 15 ¢/1000 gallons
  cooling water needed = 30 lbs/lb. steam

- cost of water in $/lb.

  $= \frac{\$\ 0.15}{1000\ \text{gallons}} \times \frac{1}{8.37}\ \frac{\text{gallon}}{\text{lbs.}}$

  $= \$1.79 \times 10^{-5}$/lb.

- lbs. of cooling water needed, P^W

  $= 30\ \frac{\text{lbs. water}}{\text{lbs. steam}} \times P^S$ lbs. steam

  $= 30 \times 698374$

  $= 20.95 \times 10^6$ lbs. water

- annual water cost

  $= C^W \times P^W$

  $= 1.79 \times 10^{-5} \times 20.95 \times 10^6$

  = $375.47

e) Electricity

- additional data

  fan power per scfm, F = 0.003 kw/scfm
  electrical cost, C^K = $ 0.04 /kwh

- annual electricity cost

  $= C^K \times F \times Q \times H$

  $= 0.04 \times 0.003 \times 3000 \times 2080$

  = $748.80

f) carbon replacement

- additional data

  price of carbon, C^C = $\$\underline{1.00}$ /lb.
  carbon replaced = $\underline{300}$ lbs. per 1000 scfm every $\underline{5}$ (n^3) years

- annual carbon replacement, P^C

  $$= \frac{300 \text{ lbs.}}{1000 \text{ scfm}} \times Q \text{ scfm} \times \frac{1}{n^3}$$

  $$= \frac{300}{1000} \times 3000 \times \frac{1}{5}$$

  $$= 180 \text{ lbs.}$$

- annual carbon replacement cost

  $$= C^C \times P^C$$

  $$= 1.00 \times 180$$

  $$= \$180.00$$

g) operation

For Manual Systems

- additional data

  hourly labor cost, C^L = $\$_____$

- labor hours needed for steam regeneration, H^L

  $$= \frac{S^{0.7}}{125} \times H$$

  $$=$$

  $$= _____ \text{ hrs.}$$

- annual operation cost, manual systems

  $= C^L \times H^L$

  $=$

  $= \$$

  For Automated Systems

- additional data

  hourly labor cost, C^L = $\$ \underline{10} /hr.$
  labor needed = $\underline{15}$ minutes per 8-hour shift

- Labor hours needed for steam regeneration, H^L

  $= \frac{15 \text{ minutes}}{8 \text{ hours}} \times \frac{1}{60} \frac{\text{hour}}{\text{minutes}} \times H$

  $= \frac{15}{8} \times \frac{1}{60} \times 2080$

  $= \underline{65}$ hrs.

- annual operation cost, automated systems

  $= C^L \times H^L$

  $= 10 \times 65$

  $= \$650.00$

h) Maintenance, Insurance and Taxes

- additional data

  Maintenance = $\underline{5}$ percent of installed cost, C^I
  Insurance = $\underline{1}$ percent of installed cost, C^I
  Taxes = $\underline{1}$ percent of installed cost, C^I

- installed cost, C^I (from a)

  $= U \times Q \times ICF$

  $= 4.67 \times 3000 \times 2.0$

  $= \$ 28,020$

- annual maintenance, insurance and tax costs

$$= \left(\frac{5}{} + \frac{1}{} + \frac{1}{}\right) \times \frac{1}{100} \times C^I$$

$$= \frac{7}{100} \times 28020$$

$$= \$1961.40$$

i) Solvent Credit

- additional data

solvent recovery, R^S = 90 percent
solvent density, D = 12.13 lbs./gallon

- solvent recovered, R

$$= \frac{R^S}{100} \times 1.67 \times 10^{-7} \times S \times MW \times Q \times H \times \frac{1}{D}$$

$$= \frac{90}{100} \times 1.67 \times 10^{-7} \times 500 \times 135.5 \times 3000 \times 2080 \times \frac{1}{12.3}$$

= 5238.3 gallons

- annual solvent credit

$$= V \times R$$

$$= 2.15 \times 5238.3$$

$$= \$11262.38$$

SUMMARY

		Annualized Cost
Capital Costs:		
a)	Package Adsorber	= $ 3684.63
b)	Space	= 595.08
		Total Annualized Capital Cost = $4279.71
Operating Costs:		Annual Cost
c)	Steam	= $ 1047.56
d)	Water	= 375.47
e)	Electricity	= 730.80
f)	Carbon Replacement	= 180.00
g)	Operation	= 650.00
h)	Maintenance, Insurance & Taxes	= 1961.40
i)	Solvent Credit	

Total Annual Operating Cost = $ 4995.23

TOTAL ANNUAL COST = $ 9274.94

= $11262.38

NET ANNUAL PROFIT (COST) = $ 1987.44

Profit (Cost) Per Operating Hour = $ 1987.44 /H

$$= \frac{1987.44}{2080}$$

=$0.96

CHAPTER VI

COMPARISON OF PROCESS CHANGES AND CONTROL TECHNIQUES

This section compares selected process changes discussed in Chapter IV (covers, increased freeboard, refrigerated chillers, and distillation) and one treatment technique from Chapter V (carbon adsorption). The process changes selected were those with test data available, and they in no way constitute all the options for change. The comparisons are made on the basis of:

- Emission reduction effectiveness of each alternative, as measured by solvent consumption;
- Profitability of each alternative; and
- Effectiveness of combined process changes and/or treatment techniques in reducing solvent consumption.

The effectiveness of covers in conjunction with other control alternatives is dependent on the frequency of vapor degreaser usage. As usage is increased from the typical 25 percent of a work shift, the effectiveness will be diminished. Further, the usage of covers and carbon adsorption requires coordination. When covers are closed, the carbon adsorber exhaust fan should be shut off to minimize the solvent's migration in—and escape from—the carbon bed.

Carbon adsorption appears to be less complimentary to process changes than some of the process changes are to each other. The reason is the dependency of carbon adsorption collection and efficiency on exhaust systems, which pull airflow from the solvent cleaners. Process changes operate more effectively under conditions where airflow is minimized.

Table 3 (originally presented in part as Table 1) shows the effectiveness of various process changes and a treatment technique (carbon adsorption), singly and in combination, in reducing hydrocarbon emissions. No combination of the process changes listed will meet an overall 85-percent efficiency. Only the combination of one or more process changes with carbon adsorption could have a chance of meeting this figure.

For example, under the best conditions, a refrigerated chiller might achieve a 60-percent emission reduction. Again, under ideal conditions a cover added to the chiller may achieve an additional 40-percent reduction of the remaining 40 percent of the emissions, i.e., 16 percent. The total emission reduction of 76 percent is still below 85 percent.

Table 3

Comparison of Process Changes and a Treatment Technique for Reducing Hydrocarbon Emissions

Emission Reduction Technique	Solvent[a] Reduction Effectiveness	Profitability	Effectiveness When Combined With Other Process Changes
Covers	24-50% 35%	Generally profitable	With Freeboard: 5-15% greater than cover With Chillers: 16-43% greater than chillers[c] With Distillation: Additive With Adsorption: Slightly additive
Increased Freeboard	27-55% 30%	Generally profitable with the exceptions of methylene chloride and trichlorotrifluoroethane where freeboards are already increased	With Covers: 5-15% greater than cover With Chillers: No data With Distillation: Additive With Adsorption: Slightly additive
Refrigerated Chillers	16-60%[b] 40% 35-77% 57%	Generally profitable with the exception of small tank on one shift operation	With Covers: 16-43% greater than chillers[c] With Freeboard: No data With Distillation: Additive With Adsorption: Not additive
Distillation	80% of disposed solvent	Profitable above 350 gallons per year of halogenated solvent	Can be combined with all other changes. Combined effectiveness is additive.
Carbon Adsorption	20-65% 40%	Profitable when inlet concentration greater than 200 ppm, depending upon solvent value	With Covers: Slightly additive With Freeboard: Slightly additive With Chillers: Not additive With Distillation: Additive

(a) Upper set of numbers is range, lower is expected efficiency. Overall effectiveness used except where noted.
(b) Two sets of test results.
(c) 16% for 1,1,1-trichloroethane and 43% for methylene chloride.

The difficulties in achieving control efficiencies of 85 percent or better, along with the difficulties in sampling solvent emissions, are among the reasons that EPA is not considering a similar regulation for new sources; for these, the Agency is studying equipment specifications and solvent substitutions, or combinations thereof.

The process changes all have a positive—and in most cases, an attractive—return on investment and should be considered for that reason irrespective of pollution control. Since any gain is due to solvent recovery, changes should be implemented on a step-by-step basis, with compliance evaluations after each step.

The suggested steps for achieving the greatest emission reduction possible (where solvent substitution is not an alternative) would be in the following order:

1. Improve solvent cleaning operating procedures.
2. Distill spent solvents.
3. Make process changes:
   - Chillers,
   - Chillers and covers, and
   - Chillers, covers and freeboard.
4. Install a carbon adsorption system.

APPENDIX A

FORM FOR CALCULATION OF CARBON ADSORPTION COST

General Design Data

Solvent: _____
Solvent Concentration, S = _____ppm
Solvent Molecular Weight, MW = _____
Solvent Value, V = $_____per gallon

Gas Flow, Q = _____ scfm
Operating Hours, H = _____per year
Adsorber Type: _____
Adsorber Unit Price, U = $_____/scfm

Annualized Capital Costs:

a) Package Adsorber

- additional data

  installation cost factor, ICF = _____
  useful life of adsorber, n^1 = _____years
  interest rate, i = _____per cent = _____(expressed as a fraction)

- capital recovery factor, CRF

$$CRF = \frac{i(1+i)^{n^1}}{(1+i)^{n^1} - 1} = \text{_____} =$$

- annualized package adsorber cost

  $= U \frac{\$}{scfm} \times Q \text{ scfm} \times ICF \times CRF$

  =

  = $

b) Space

- additional data

  unit area occupied by adsorber, A = _____sq.ft./scfm
  cost per square foot of space, C^A = $_____/sq.ft.
  useful building life, n^2 = _____ years

- capital recovery factor, CRF

$$CRF = \frac{i(1+i)^{n^2}}{(1+i)^{n^2} - 1} = \text{_____} =$$

- annualized space cost

$= A \ \frac{\text{sq. ft.}}{\text{scfm}} \times Q \text{ scfm} \times C^A \ \frac{\$}{\text{sq.ft.}} \times CRF$

=

= $

Operating Costs

c) Steam

- additional data

cost of steam, C^S = $_____/lb. steam

- lbs. of steam needed, P^S

$= (78 + 0.04\ S^{1.085})\ 10^{-3} \times ? \times H$

=

=

= _____ lbs.

- annual steam cost

$= C^S \times P^S$

=

= $

d) Water

- additional data

  cost of water, C^W = _____ ¢/1000 gallons
  cooling water needed = _____ lbs/lb. steam

- cost of water in $/lb.

  $= \frac{\$_____}{1000 \text{ gallons}} \times \frac{1}{8.37} \frac{\text{gallon}}{\text{lbs.}}$

  = $_____/lb.

- lbs. of cooling water needed, P^W

  = _____ $\frac{\text{lbs. water}}{\text{lbs. steam}} \times P^S$ lbs. steam

  =

  = lbs. water

- annual water cost

  $= C^W \times P^W$

  =

  = $

e) Electricity

- additional data

  fan power per scfm, F = _____ kw/scfm
  electrical cost, C^K = $ _____/kwh

- annual electricity cost

  $= C^K \times F \times Q \times H$

  =

  = $

f) carbon replacement

- additional data

  price of carbon, C^C = \$_____/lb.
  carbon replaced = _____lbs. per 1000 scfm every _____(n^3) years

- annual carbon replacement, P^C

  $= \frac{\text{lbs.}}{1000 \text{ scfm}} \times Q \text{ scfm} \times \frac{1}{n^3}$

  =

  = lbs.

- annual carbon replacement cost

  $= C^C \times P^C$

  =

  = \$

g) operation

For Manual Systems

- additional data

  hourly labor cost, C^L = \$_____

- labor hours needed for steam regeneration, H^L

  $= \frac{S^{0.7}}{125} \times H$

  =

  = _____ hrs.

- annual operation cost, manual systems

  $= C^L \times H^L$

  =

  = $

  For Automated Systems

- additional data

  hourly labor cost, C^L = $_____/hr.
  labor needed = _____minutes per 8-hour shift

- Labor hours needed for steam regeneration, H^L

  $= \frac{\text{minutes}}{8 \text{ hours}} \times \frac{1}{60} \frac{\text{hour}}{\text{minutes}} \times H$

  =

  = _____hrs.

- annual operation cost, automated systems

  $= C^L \times H^L$

  =

  = $

Maintenance, Insurance and Taxes

- additional data

  Maintenance = ___percent of installed cost, C^I
  Insurance = ___percent of installed cost, C^I
  Taxes = ___percent of installed cost, C^I

- installed cost, C^I (from a)

  $= U \times Q \times ICF$

  =

  = $

- annual maintenance, insurance and tax costs

  = (_____+_____+_____) x $\frac{1}{100}$ x C^I

  =

  = $

i) Solvent Credit

- additional data

  solvent recovery, R^S= _____percent
  solvent density, D = _____lbs./gallon

- solvent recovered, R

  = $\frac{R^S}{100}$ x 1.67 x 10^{-7} x S x MW x Q x H x $\frac{1}{D}$

  =

  = _____gallons

- annual solvent credit

  = V x R

  =

  = $

SUMMARY

	Annualized Cost
Capital Costs:	
a) Package Adsorber	= $
b) Space	=
	Total Annualized Capital Cost = $
Operating Costs:	Annual Cost
c) Steam	= $
d) Water	=
e) Electricity	=
f) Carbon Replacement	=
g) Operation	=
h) Maintenance, Insurance & Taxes	=
i) Solvent Credit	
Total Annual Operating Cost	= $
TOTAL ANNUAL COST	= $
	= $
NET ANNUAL PROFIT (COST)	= $
Profit (Cost) Per Operating Hour	= $_____/H
	= _____
	=

BIBLIOGRAPHY

1. DOW Chemical Company, *Study To Support New Source Performance Standards For Solvent Metal Cleaning Operations.* Prepared for Office of Air Quality Planning, U.S. Environmental Protection Agency, June 30, 1976.

2. EPA Office of Air Quality Planning and Standards, *Control of Photochemical Oxidants – Technical Basis and Implications of Recent Findings.* EPA-450/2-75-005, July 1975.

3. Perry, J. H., and Chilton, G. H., *Chemical Engineers' Handbook,* 5th Ed., Part 3. New York: McGraw-Hill Book Co., 1973, p. 250.

4. Rekstead, C. M., "Upheaval In Vapor Degreasing." *Factory,* Jan. 1974, pp. 27-32.

5. *Handbook of Vapor Degreasing.* American Society For Testing and Materials, STP 310A, April 1976.

6. Danielson, John (ed.), *Air Pollution Engineering Manual,* U.S. Environmental Protection Agency, AP-40, 2nd Ed., May 1973.

7. Kovach, J. Louis, "Principles of Adsorption." *Control of Gaseous Emissions,* Air Pollution Training Institute, U.S. Environmental Protection Agency, Jan. 1973.

8. Cheremisinoff, Paul N., P.F., "Control of Gaseous Air Pollutants." *Pollution Engineering,* May 1976, p. 30.

9. Manzone, R. R., and Oakes, D. W., "Profitability of Recycling Solvents From Process Systems." *Pollution Engineering,* Vol. 5, No. 10, Oct. 1973, pp. 23-24.

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